University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

Comparison of Robotic Total Stations for Scanning of Volumes or Structures

A dissertation submitted by

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In fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Spatial Science: Surveying

Submitted: 29 October 2009

ABSTRACT

Today's society demand faster, easier, safer and more accurate spatial information than ever before. Over the past 15 years surveyors have seen the introduction of reflectorless technology and more recently, laser scanning. Reflectorless technology and laser scanning has become a useful tool in many surveying applications. This technology has opened the door to the majority of demands that the community and other surveyors request. Due to this evolving technology specific laser scanning instruments have been developed. These instruments can cost in excess of half a million dollars and require specific software. In recent times companies have introduced laser scanning capabilities into total stations to reduce costs and integrate technology, which has launched the new evolution in total stations with most now having reflectorless and scanning capabilities included within the instrument.

This project was undertaken to address surveyor's uncertainties regarding reflectorless technology and laser scanning capabilities within total stations. A number of tests were conducted by both the Leica 1205R and the Trimble S6 instruments to compare both accuracy and performance. The three tests performed varied from simple point comparisons to scanning of volumes and the measuring of building encroachments. The results found there to be very small errors when performing simple point comparisons over a small range. The total stations also performed very well in the volume scans as both instruments produced similar results. Lastly, some problems were found with the encroachment testing as software capabilities limited my outputs. Both reflectorless and the laser scanning capabilities performed very well allowing me to test and analyse their full potential.

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ENG4111 Research Project Part 1 &

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Signature

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Date

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Mr. Kevin McDougall, from the University of Southern Queensland Faculty of Engineering and Surveying, for his advice and guidance. I would like to acknowledge his time and help given during the duration of this project.

I would also like to acknowledge the University of Southern Queensland Faculty of Engineering and Surveying for providing the equipment and Mr. Clinton Caudell for all of his help with using the equipment during this project.

Finally I would like to thank family, friends and Krysten Cunningham for their help and support during the year and the duration of my degree.

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GLOSSARY OF TERMS

3D - Three Dimensional: A description of the spatial environment in reference to its three dimensions.

Total Station: An electronic optical measuring unit used within modern day surveying.

EDM - Electronic Distance Measurement: A device that measures the distance from an instrument to an object by the use of a prism.

Reflectorless Total Station: A device that measures a distance to an object without the need of a prism to reflect.

Accuracy: The degree of closeness of a measurement to the true value.

Precision: The degree of repeatability of measurements under unchanged conditions that show the same result (may not be accurate).

Point Cloud: An array of three dimensional points in space.

Chapter 1 – Introduction

1.1 Outline

This chapter will provide an outline of the project background, research problem, objectives and justification for this project. The dissertation will describe some of the fundamental characteristics of reflectorless technology, laser scanning and the specifications of the chosen robotic total stations. It will also cover in detail the comparisons between the robotic total stations in regards to their scanning capabilities of volumes and structures. This technology is relativity new to the present time so there is a need to increase the awareness of it and perhaps to solve answers and create new questions for further developments in this field.

1.2 Project Background

In society today there is a demand for faster, easier and safer technology and methods. While fulfilling the role as spatial scientists there is a definite need to gather information ‘faster’, understand the operation of a wide range of instruments and methods to perform surveying applications ‘easier’ and to allow the collection of data where other methods could not vantage ‘safer’. Technology within spatial science has evolved rapidly over the past ten years by refining the above needs not only for surveyors but general society as well. Changes are evident with the successful introduction of technology into the spatial science industry. An example of this is the Global Positioning System (GPS) which is now seen as a must have device for many surveying applications. GPS introduced methods of measurement from satellites without the need of traditional traversing. From the introduction of this new technology questions were raised of its capabilities. These questions included the following: What range of accuracies does it achieve? Is it affected by obstructions? Will this technology be useful to anyone?

After research was carried out, the spatial science industry saw GPS as a standalone application and the next revolution in surveying methods. We are now one step further into the future with GPS integrated into total stations and the inclusions of robotic and reflectorless technology which exist in standalone systems incorporating all functions.

A relatively new development in technology is ground-based laser scanning also known as terrestrial laser scanning. Laser scanning has evolved from reflectorless and robotic technology. It is the next generation of automated surveying. Laser scanning provides faster data capture, easier setup and use of equipment and allows collection of data where other methods could not vantage. This means it is also safer for users. By meeting the current needs of today's society, spatial science industries can now perform more tasks at a reduced cost and time.

Laser scanning is becoming increasingly popular for many applications including the monitoring of features and objects. Scanners are used to monitor high wall movements in mine sites as they do not require a surveyor on the high wall. The scanner can record thousands of points automatically and the risk of injury to operators and assistants is minimised. Consequently, the need is increasing to start testing and comparing this new technology so it is guaranteed to meet professional and performance standards not only for the surveyors utilising it but also for the clients involved in the project.

As the name suggests reflectorless technology does not require the use of a reflector or prism to record the distances. Measurements are made by the instrument emitting a beam of light towards a feature where it is reflected back to the instrument and a distance is then calculated. There are two types of measurement; pulsed time of flight (TOF) and phase based. These will be explained in greater detail later. Reflectorless technology does have some limitations that need to be researched and these will also be explained in greater detail further into this project paper.

Robotic total stations allow the control over an instrument via remote control generally from the reflector's range pole. The operator can control the instrument by the remote control connecting to the instrument wirelessly. This can remove the need for an assistant field hand as the operator can complete the task by themselves.

1.3 Statement of Problem

Although reflectorless technology has been around for a number of years, there has been limited testing and availability of this technology. Problems encountered with reflectorless technology include its effect on different materials, colours and distances as well as safety issues and the uses of the technology. Upon investigating these problems I hope new techniques will arise for further research and testing for continuing projects.

1.4 Project Aim

This project seeks to compare the laser scanning capabilities and reflectorless limitation of two robotic total stations for various surveying applications.

1.5 Objectives

The key objectives of this project are:

i. To research the existing laser scanning technology, capabilities and specifications of both the Trimble S6 and Leica 1205R.
ii. Identify a rigorous testing regime (speed, accuracy etc) and range of possible testing applications including stock piles, buildings and vegetation.
iii. Test the scanning capabilities on various features including soil, structural features (roof heights, floor heights and window frames) and point comparisons under different conditions.
iv. Analyse the outcomes of the test according to a range of criteria.
v. Discuss the implications of the results with respect to surveying organizations and potential opportunities.
vi. If time permits extend the range of scanning tests and situations.

1.6 Justification

It is important to realise the full capabilities and limitations of laser scanning and reflectorless technology. Many people within the surveying industry are not aware of errors and the uses these instruments are capable of performing. This project will test performance, accuracy, applications, comparisons and modelling. These are the necessary tools for laser scanning and reflectorless applications. It is essential to provide awareness and real application results to provide information to the user which is the intention of this project.

1.7 Summary: Chapter 1

As the project aim states this project will seek to compare the laser scanning capabilities and reflectorless limitation of two robotic total stations for various surveying applications. This project will review all available literature on the technology of both laser scanning robotic total stations and the theory behind how they work. It is anticipated that by the end of this dissertation the results will provide answers to the objectives listed above and solve the problem encountered.

Chapter 2 – Literature Review

2.1 Introduction

This chapter will outline the relevant literature associated with reflectorless total station scanning. It will also examine the technology of how reflectorless and laser scanning operates. There is limited research that has been conducted on laser scanning with robotic total stations, however there has been a considerable amount of research on laser scanning in general. This review will provide the theory behind this technology, its history and current uses.

2.2 Principle of Electronic Distance Measurement

Accurate measurements are very important in today's surveying and engineering society where we see countless disputes between where boundaries are located and buildings are set out and also the need for accurate measurement of volumes. The need for very accurate measurement is important as a base for any surveying applications. Besides the plumb bob and tape, there are two basic forms of measurement used by a total station. These two measuring types are pulsed time of flight (TOF) and phase shift. Both these methods are used to achieve the same result which is to take accurate measurements. They both achieve the same goal however they use two different methods to achieve this. Although both methods look to achieve the same goal, they both have their advantages and disadvantages in different applications. Some instruments now are offering the option of both methods which gives the option back to the surveyor to decide. The surveyor is therefore not limited or disadvantaged without the other.

2.2.1 Pulsed Time of Flight Measurement

Pulsed time of flight (TOF) measurement is an active mode of measuring where the instrument emits its own source of energy. In comparison, a passive mode of measurement relies on an external source of energy e.g. the sun. TOF measurement works by emitting a light pulse of energy towards an object or surface that is being measured. This pulse is timed from when it leaves the light emitting device to when it is reflected back from the object to the instrument. Because the time (t) of the pulse is recorded to and from we have to half the time to get the distance to the object. Equation 2.1 outlines the calculation method. Distance, ρ, is found by speed of light, c, multiplied by time of fight, t, divided by two.

$$P = (c * t) / 2 \qquad \text{(Equation 2.1)}$$

Pulsed TOF method uses wide cone like laser pulses which is useful for long range measuring but not as effective for short range measuring. This can also have an effect on the accuracy of the measurement. This type of measurement method is also dependant on the accuracy of the speed of light. In general terms, the speed of light is measured in a controlled vacuum, whereas real world situations are not in a controlled environment. Speed of light when passed through different materials, weather and surfaces will change the speed of the light. TOF method is also more tolerant to interference of the beam. Due to further refining of this technology the difference in accuracy has now become insignificant (Hoglund & Large 2005).

2.2.2 Phased Shift Measurement

Phased shift measurements are calculated in a similar way to an EDM in older total stations. Instead of using a laser light pulse like TOF, they transmit a modulated optical measuring beam also know as a sine wave type beam (see figure 2.1). This beam is emitted from the EDM towards a surface where it is reflected back to the EDM. This allows for the comparison between the original sine wave and the reflected sine wave producing a horizontal shift between waves called a ‘phase shift’. This phase shift can then determine the distance travelled from the length of one cycle by the number of cycles shifted.

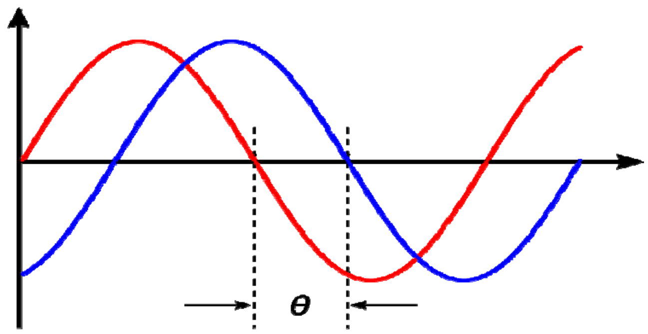

Figure 2.1: Phase Shift (θ) used to calculate distance travelled.
Source: (Wikipedia n.d. a)

Phase shift measurement is considered to have a greater accuracy compared to the TOF method. This is because the beam has a narrow field of view and it is not affected by as many variables. However, the phase shift method is known to have a limited range and is affected by interference which therefore makes it less desirable to users to perform these measurements (Hoglund & Large 2005).

Reflectorless measurement can be seen as a form of remote sensing application. Remote sensing can be defined as the science, art and technology associated with the acquisition and analysis of data about an object, area or phenomenon without direct contact. This definition has similar characteristics to reflectorless measurement used by laser scanning (Mather 2004).

2.3 Characteristics of Electromagnetic Radiation (EMR)

2.3.1 Electromagnetic Wave (EM)

An electromagnetic (EM) wave (see figure 2.2) has two properties, the first being an electrical field which varies in magnitude perpendicular to the direction of travel. The second component is a magnetic field which varies in magnitude at right angles to the electrical field. Both fields travel at the speed of light.

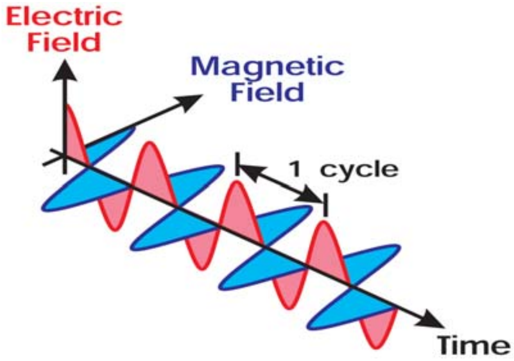

Figure 2.2: Electromagnetic Wave
Source: (National Research Council Canada 2006)

2.3.2 Electromagnetic Radiation

Electromagnetic radiation (EMR) is a form of energy that has the properties of a wave. Electromagnetic radiation has two components namely wavelength and frequency. Wavelength is the length of one cycle and the frequency is the number of wave cycles that are repeated per time period. From figure 2.3 below it can be seen that the wavelength is the shortest towards the Gamma Ray end of the spectrum giving out a higher frequency. Whereas, at the opposite end of the spectrum towards the radar and infrared regions the wavelengths are longer and have less frequency.

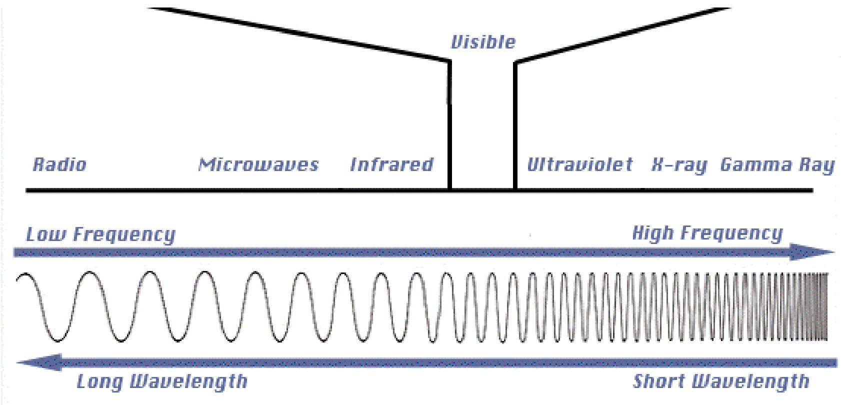

Figure 2.3: Electromagnetic Spectrum, with frequency and wavelength properties.
Source: (University of Minnesota n.d.)

Different wavelengths play a major role in how features are gathered and represented when EMR is used for measurement. If you have ever seen a photograph of vegetation studies you will often see that the photo will misrepresent the true colours of vegetation. They will be either displayed in fluorescent green or red. This is because different features are detectable by different wavelengths. In this case vegetation has high reflectance in the infrared red spectrum allowing us to control what colours will be shown for that region. Figure 2.4 represents a spectrum which is a region defined by the measurement nanometres or terahertz and this is called the electromagnetic spectrum. Electromagnetic spectrum is a range of all possible electromagnetic radiation frequencies.

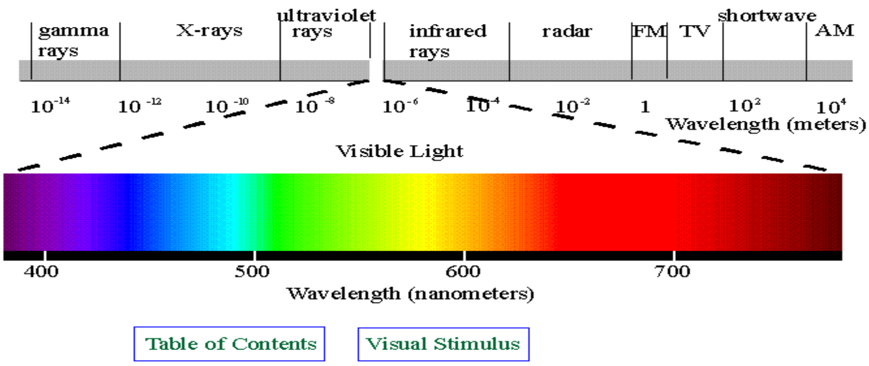

Figure 2.4: Electromagnetic Spectrum.
Source: (South Carolina Department of Natural Resources 2009)

The visible light region ranges from 380nm to 760nm. This region on the spectrum is where the wavelength is the strongest and most sensitive to our eyes. Humans cannot see any other part of the spectrum beside the visible light region.

2.3.3 EMR Interactions

Various effects like scattering, transmission, atmospherics and absorption can influence the path or return signal of a wavelength. Scattering is the affect that a surface has on a wavelength. There are two types of scattering these are specular and diffuse. Figure 2.5 represents specular type reflectance which often occurs on smooth surfaces. This happens when the signal is reflected back in a mirror like form. Figure 2.6 shows diffuse reflectance occurring on rough surfaces making the signal reflect in different directions.

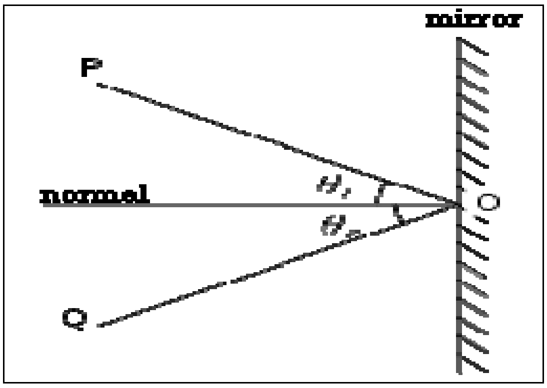

Figure 2.5: Specular Reflection.
Source: (Wikipedia n.d. b)

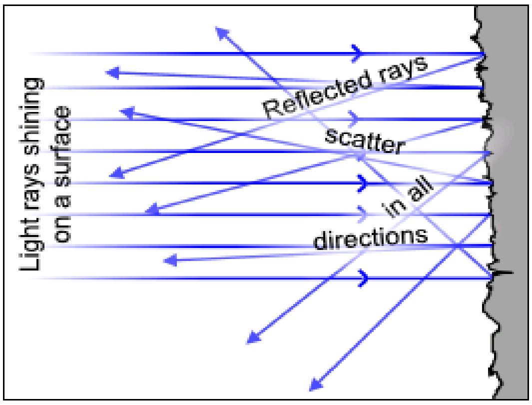

Figure 2.6: Diffuse Reflection.
Source: (Wikipedia n.d. c)

Figure 2.7 represents the four different effects of EMR interactions. Transmission occurs when the EM radiation passes through the material/object without interaction, like glass. The path can either be deflected or refracted as it passes through various density materials. This can have an effect on the velocity and wavelength of the EM radiation. Absorption occurs when the EM radiation is absorbed into the feature being targeted. All surfaces and features absorb some amount of the EM radiation when it is scanned. Some features though will absorb more EM radiation than others. The best conductor of EM radiation is water. A good example of this conduction is when you look down to the ocean from a plane in the air and you can see the dark blue tone in the water. This is actually because the water absorbs all the EM radiation from the sun giving the impression of dark blue water.

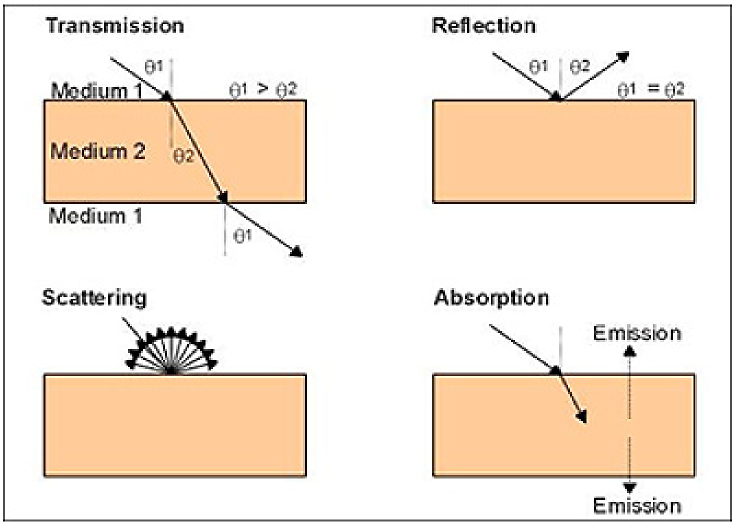

Figure 2.7: EMR Interactions
Source: (Globe GIS n.d.)

2.3.4 Reflectance

Reflectance depends on a number of factors including the material, surface, materials constituting the surface (water) and non-reflective surfaces. It is important to know what affects these factors can have on EM radiation so proper corrections and awareness is understood. Reflectance can be used to tell the user what kind of material or surface has been recorded. For example, if you were to measure two surfaces of snow and dark soil, the reflected EMR will return different levels of energy. The snow surface will reflect a high amount of EMR whereas the dark soil will reflect a low amount of EMR in the visible waveband. This can be used by analysts to determine what has been recorded and the properties associated to that recorded data.

Reflectance is measured by the amount of EMR (otherwise known as incident radiation) that is reflected back to the sensors device. Reflectance of EMR is affected in three ways. The effects of the emitted radiation, effect of the surface or materials constituting the surface and the effects on the reflected radiation. Atmospherics can influence the radiation of the incident and reflected radiation, but for terrestrial laser scanning the effects are very minor, approximately 1ppm which equates to 1mm over 1 km/degree (Mather 2004).

2.3.5 Surfaces & Material

Most surfaces and materials can be divided into the two common forms of scattering being specular and diffuse. Specular surfaces and material will usually occur where the EMR is reflected from relativity smooth objects like metal, walls, concrete and any polished surfaces or coverings. Whereas, diffuse scattering will occur as EMR reflects from rough surfaces and materials like asphalt, rendered bricks, rocks & dirt and jagged features.

2.3.6 Colours

Coloured surfaces also absorb and reflect EMR. Colour is used in many ways to define features and give objects identification. Reflectance is affected by moisture, natural characteristics and different properties of the feature. For example, chlorophyll which is a chemical of leaves will absorb the blue and red energy thus reflecting the green wavelength. If the plant is stressed or matured, it will contain less chlorophyll, resulting in less absorption and more reflection in the red energy waveband. Like all other factors colour must be taken into account when analysing EMR (Mather 2004).

2.3.7 Wet Surfaces

One material that is an excellent conductor of EMR is clear water. Figure 2.8 shows how water absorbs all EMR in the infrared (IR) band and only reflects a small amount of EMR in the visible band. This is due to water being transparent and the absorption of EMR. As the EMR reaches the water it absorbs it and transmission scattering causes the radiation to scatter in all directions converting it into other forms of energy. As mentioned above, clear water is an excellent conductor of EMR. However, sometimes there is no need to measure clear water and instead just the things that are suspended within it. Turbid water contains materials that are suspended within it including dirt, sediments and algae. These suspended materials cause EMR to reflect. Although it causes EMR to reflect the reflection is dependent on how turbid the water is and what materials are being reflected. As surveyors the need to measure water is not a common target except for surfaces that may contain water particles like dew or light rain. These water particles may cause small amounts of refraction from one medium to the next altering the path of the radiation.

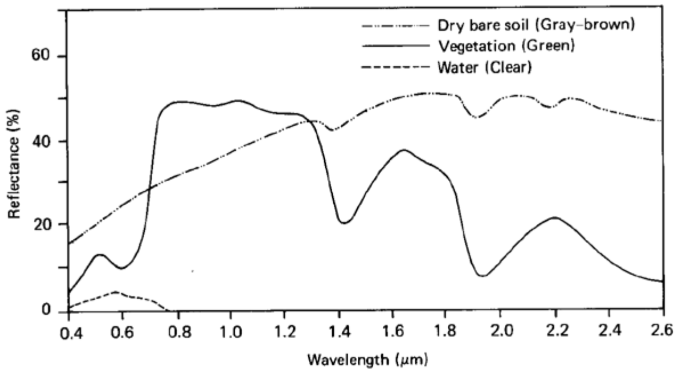

Figure 2.8: Typical Spectral Signatures
Source: (Google n.d.)

2.3.8 Non-reflective Surfaces

Not all EMR will reflect from every surface. Non-reflective surfaces include plain glass, light coverings, windows, mirrors and water. The effects these surfaces have on EMR are transmission scattering, where the radiation passes through the surface and reflects from the next object it comes into contact with. As explained above, water has very little reflection or sometimes none in the visible band. Plain clear glass will not reflect any amount of radiation, but will refract the light radiation as it passes through the glass. This refraction can cause the light beam to refract so far that it will not reflect back to the instrument. In most cases this will be the reason why radiation is not recorded by a laser scanning instrument.

2.4 Reflectorless Technology

Technology is continually evolving within the surveying industry with many new instruments and methods being developed all the time. The method of measurement used within surveying began with the use of the Gunter's chain until surveyors saw the introduction of the flat steel tape. Technology continued to progress with the use of electronic distance measurement (EDM). EDM emits a light wave beam from a device which then reflects from a prism target back to the EDM device. It then proceeds to calculate the distance acquired by the reflection. Nowadays, due to 21st century technology the limitation of the prism has been removed with the introduction of direct reflex (DR). This is also known as reflectorless which now sees measurement taken directly to features without the use of other tools (Department of Environment and Resource Management 2007).

Reflectorless technology has become essential to many surveyors in the industry. It is able to provide numerous beneficial factors including the following:

- The ability to record information of features that might not have been accessible before due to safety issues.
- Automated systems and sole operators.
- Time & costs.

While reflectorless technology is relatively new to surveying, the technology has been around for quite some time. The latest trend of reflectorless technology has seen almost all instruments now incorporate reflectorless technology as a standard into surveying instruments. Reflectorless technology is opening a new door in one-person surveying. By having reflectorless capabilities, GPS and robotics all integrated into the one system there is no need for a traditional chainman. This increases the speed of the work performed and also to some degree it improves accuracy and time efficiency.

2.5 Laser Scanning

Laser scanning can be defined as the scanning of a surface by the means of EM pulses of energy that are measured by a laser scanning instrument. This then creates three-dimensional (3D) points of data. Data is achieved by remotely sensing horizontal & vertical angles and reflected distances. The data is in the form of X,Y,Z coordinates which are based from the set parameters within the instrument. This data can then be used to represent the real world in the form of coordinates for the analysis of information and design on a computer display. Unlike most traditional surveying instruments and methods, laser scanning can be performed any time of day or night and also in varying weather conditions like rain or fog.

There are two main forms of platforms that laser scanners use which are terrestrial and airborne laser scanners. Airborne laser scanning uses a plane or helicopter as a platform and performs scanning from the sky. Terrestrial laser scanning uses platforms on the earth's surface otherwise known as ground based. These platforms come in the form of total station scanners and laser scanner units. They are used to perform everything that an airborne laser scanner does but for ground features. Some uses of terrestrial laser scanning are:

- Scanning cultural heritage features.
- Archaeology studies and documenting.
- Modelling building and structures.
- Volumetric calculations of open and underground mining.
- Forensic crime scene investigation.
- Deformation monitoring of surfaces and structures.
- Engineering and constructed surveys.
- Monitoring of forestry, glaciers, landslides and dam walls.
- Virtual reality computer games and animated walkthroughs.
- Vegetation studies of growing rates and density studies.

These are just some of the uses of laser scanning. As research in this field expands, new problems will arise and greater software will become available hopefully at cheaper prices. A laser scanner will very soon become an everyday tool in the collection of remote data.

The scanning ability in total stations today is becoming more and more automated. This means that the operator sets it, defines some required parameters and lets it scan. When comparing laser scanning to traditional surveying methods, there is not a great deal of difference between the theoretical foundations. They both achieve X, Y, Z point data, they both need computer analysis and they both produce the same project result. However a laser scanner requires only one field technician, can scan up to 50,000 points a second, has an automated data system and takes measurements to locations not accessible (See figure 2.9).

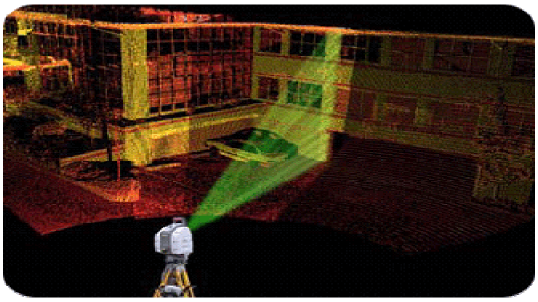

Figure 2.9: Laser Scanning Unit
Source: (Google 2009)

2.5.1 Object Recognition

Analysis of gathered data can be quite difficult in some situations. Point data is displayed as points on a computer screen in relation to the coordinates recorded. So how do we know what each point represents? Without any prior knowledge of the scanned area this would prove to be difficult. After some lengthy human analysis it can be determined that points along common features like the edge of a building for example can be defined. Features like window frames and roof guttering can start to be distinguishable. This type of recognition can take quite some time and become really frustrating. New software technology has recently evolved enabling computer software to recognise point features along common lines and distances.

The software analyses and interrogates the data to find the trends and occurrences of point data. For example, if a wall was to be scanned and it had a photo frame hanging on it, the software could be used to define this feature. The software is capable of recognising the straight line edges of the photo frame. This in conjunction with the comparison of the vertical plane of the wall to the points on the frame can determine that the points are raised away from the plane of the wall. If the software recognises the wrong features this can still be undone and the drafter can manually adjust the data. This software is not available with all drafting programs and is currently still in development stages.

2.5.2 Accurate Feature Measurements

Accuracy to measure features will differ depending on the objects shape and location. Many surveyors would not think of how the laser has an effect on features around an object. Let's take measuring the corner of a building for example. Line of sight would be set to the corner of the building and the measurement is taken. It would be assumed that the distance was measured to the corner but this is incorrect. Due to the divergence of the laser beam it will spread wider the further it travels from the instrument. Therefore, it will in fact reflect from the sides of the wall and not the intersection of the two walls. (See figure 2.10).

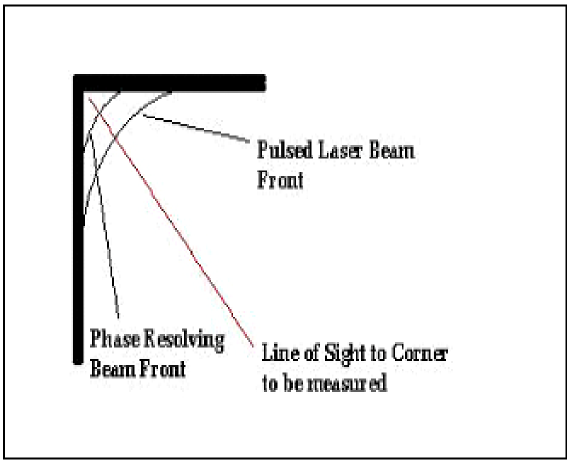

Figure 2.10: DR Corner Measurement Effect
Source: (Hoglund & Large 2005)

Both types of measuring have some ranging error. The phase based method achieves a closer measurement to the corner than the Time of Flight method. Measuring accurate angles is not affected by the sides of the building. Oblique measurements however may affect both angles and distance measurements. When sighting a corner from an oblique angle the line of sight may be skewed along the face of the building which then affects the judgment of the corner. This will also affect distance measuring as seen below on a circular object. Part of the beam may miss the side of the object taking the measurement to the next feature behind. This will result in an incorrect calculation of the mean distance to the object. (See figure 2.11).

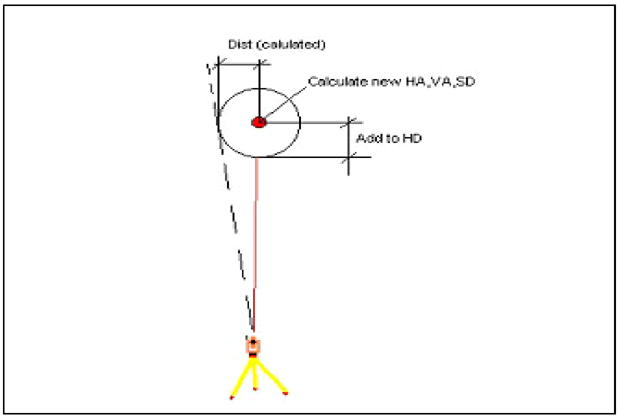

Figure 2.11: Eccentric Point Measurement.
Source: (Hoglund & Large 2005)

2.6 Reflectorless Issues & Industry Problems

Surveying industries are faced with many problems every day, whether it is instrument problems, project task problems or limitations due to Workplace Health & Safety (WH&S). Hence there is the need for researchers and problem solving personnel to create new methods or equipment to assist with these troublesome applications. Three applications have been identified from general day to day surveying tasks.

1. Volume scans: This involves the scanning to features that are restricted by WH&S. They may be restricted due to surveyors in high places, physically unable to reach the area or limited by equipment eg, cost of a laser scanning instruments. The scanning of volumes in mines is very important and requires a high level of accuracy. Because the materials they gather are exchanged for money. Consequently, there is a need to understand the limitations and accuracies of reflectorless scanning.
2. Building encroachments: This is where a building or feature has extended beyond its property boundaries to encroach onto a neighbouring allotment or crown land. For example ‘The Gabba’ in Brisbane sees part of the building encroached onto the street reserve being crown land. As surveyors we have to notify both the crown and the land owner and show the encroachment on a plan. Due to the complexity of the encroachment, traditional surveying

methods would be expensive and difficult to exercise. This would see the use of reflectorless technology to scan the area of the building encroachment in relation to the boundaries.

3. Inaccessible areas: From the above two applications inaccessibility is a major factor in some surveying tasks. Measuring points of a high rise building or even clearances of power lines from trees are virtually inaccessible by traditional survey methods due to high costs.

Reflectorless technology and scanning may be the best options for the above tasks, but there are still some imperfections with this technology. Some issues include the scanner captures too much data resulting in a long processing time. The ability to analyse the data in real time and get results straight from the instrument. Also not all materials reflect EMR and if a point does not reflect then the instrument keeps trying to scan the point. From these three application problems I have chosen to conduct small test designs to highlight the potential problems and methods for overcoming them.

2.7 Summary: Chapter 2

In summary, this literature review has explored the technology used in the undertaking of this project. This chapter has explored the background technology of reflectorless measuring, laser scanning capability and the interaction EMR has with various surfaces and materials. Research into this technology has warranted tests of how the technology can be used effectively and the capabilities it may offer. The information in this review has underlined the proceeding chapters and was used to create the tests designs within the methodology.

Chapter 3 – Methodology

3.1 Introduction

At present the principles, limitations and standards of robotic total station laser scanning are limited to the general surveyor. Consequently, the opportunity has arisen to research the capabilities, limitations and test this new technology over different scenarios and problems. The aim of this chapter is to provide an understanding of how this technology works over a number of features and also outline the field and office techniques that underpin it. Explanation of the test sites that were used and how the instruments went about the process are also discussed. The desired outcome of this methodology is to compare both the Leica TCRP 1205 + R1000 & Trimble S6 on the same test designs and provide users with performance feedback on the technology.

3.2 Equipment

3.2.1 Trimble S6 DR300+

The Trimble S6 is one of two total stations used for data acquisition within this project. The S6 is a fully robotic instrument which caters for traditional survey applications and more. The capabilities of the S6 include reflectorless technology, onboard data storage, motorised robotic controlling and many other features. The S6 comes with a detachable controller screen interface for connection to computers, robotic rover and GPS units. The Trimble CU controller comes with up-to-date software for easy use between applications. The feature of the Trimble S6 that this project is mainly concerned with is the application called “surface scan”. Surface scan allows you to define the area that is to be scanned and the instrument will robotically scan the area with rapid point capture. It will also store all the data in the onboard memory card for easy downloading and analysis. This data can be viewed in notepad, Microsoft XL, Terramodel and other drafting software. Angle and distance measurement accuracy ranges from 2” – 5” angle measurement and 3mm with prism

& 3 mm – 5 mm reflectorless distance measurement. Field techniques have not altered a lot which means that many traditional methods are still used today. Many new technologies like robotic are utilised where possible. The S6 has many capabilities including stakeout & roading, detail pickup, traversing, surface scanning and many others. For a full range of specifications, accuracy, capabilities please refer to Appendix B: Trimble S6 Datasheet (Hoglund and Large 2005).

Figure 3.1: Trimble S6
Source: (Hoglund & Large 2005)

3.2.2 Magdrive

Trimble's new magdrive technology is based upon using electromagnets for vehicular propulsion (Lemmon & Jung 2005). The concept of magnets controlling the internal movements of a total station is relatively new to surveying but the technology has been around for centuries. The technology was first introduced in 1934 where Hermann Kemper devised the idea of a magnet driven train. From there on the technology has developed to the inclusion into total stations. Magdrive technology allows for easy rotation of two plates (top and bottom) within a total station. This frictionless, high accuracy and high turning speed technology allows quick and easy surveying. The system works by two magnets which are fixed horizontally on top of each other with an air gap between them. This allows the two magnets to be frictionless while still having the affect of movement. The instrument is driven by a servo drive which uses electromagnetic force to apply rotation. This method has proven to be very accurate in holding a fixed position or as a robotic system. The magdrive technology is very quick in turning and tracking.

3.2.3 Leica TCRP 1205 + R1000

The Leica TCRP 1205 + R1000 is the second instrument used for comparison within this project. The Leica instrument is also fully robotic which includes all the necessary features to carry out all surveying applications. Similar to the S6, Leica has reflectorless technology, onboard data storage, motorised robotic controlling and many other features. The Leica display unit comes with a dual colour screen display for easy use and appearance. The instrument can also be used in conjunction with a robotic smart pole unit for on-the-fly measurements and an integrated GPS unit. All data is viewable on various software applications and Leica also provide an easy single package called Leica Geo Office. The scanning program used is called "Reference Line". It works by defining a reference scan line which then allows you to define the scanning parameters. Once these parameters have been defined the instrument can perform the scan of the area. The instrument's software allows measurement spacing intervals to be set and a real time colour display of points recorded. All data is stored in the onboard memory card which can be connected to the computer for data transfer. Angle and distance measurement accuracy ranges from 5" angle measurement and 1 mm – 3 mm with prism & 2 mm – 4 mm reflectorless distance measurement. Field techniques are similar to the S6 with the only differences in software and procedures. The Leica has many capabilities including stakeout and roading, detail pickup, traversing, reference lines and many others. For a full range of specifications, accuracy and capabilities please refer to Appendix C: Leica TPS1200+ Datasheet (Hoglund & Large 2005).

Figure 3.2: Leica 1205R + R1000
Source: (Leica Geosystems 2009)

3.2.4 Robotic Total Station Comparison

In comparison both instruments have very similar features, capabilities and applications. They are so similar that the main differences between them are the colour, shape, brand, onboard software and display. Both instruments achieve the same accuracy for angle and distance measurement. The Trimble S6 has been designed to be more user friendly with easy setup and measuring. Compared to the Leica 1205R this instrument is a little hard to control but that is based on the individual user.

3.3 Comparison

3.3.1 Reflectorless Distance Measurements

Table 3.1: Comparison between instruments over a range of categories.
Source: (Leica Geosystems 2009 & Trimble 2009)

Categories	Trimble S6 DR300+	Leica TCRP 1205+ R1000
Kodak Gray Card, 90% reflective:	> 800 m	600 m (Object in strong sunlight, severe heat shimmer.) 800 m (Object in shade or sky overcast.) > 1000 m (Underground, night and twilight.)
Kodak Gray Card, 18% reflective:	>300 m	300 m (Object in strong sunlight, severe heat shimmer.) 400 m (Object in shade or sky overcast.) > 500 m (Underground, night and twilight.)
Concrete	300–400 m	N/A
Wood construction	200–400 m	N/A
Metal construction	200–250 m	N/A
Light rock	200–300 m	N/A

Dark rock	150–200 m	N/A
Reflective foil 20 mm	800 m	N/A
Reflective foil 60 mm	1600 m	N/A
Shortest possible range	2 m	1.5 m
Longest possible range	1600 m	1200 m
Laser Beam	Pulsed laserdiode 870nm, laser class 1, Laser pointer coaxial (standard) laser class 2	Coaxial, visible red laser, Carrier wave: 660 nm. Measuring system Pinpoint R400/R1000: basis 100 MHz – 150 MHz
Angle accuracy	5" (1.5 mgon)	5" (1.5 mgon)
Distance accuracy	3 mm + 2 ppm or 5 mm + 2 ppm, standard	2 mm + 2 ppm (reflectorless < 500 m), 4 mm + 2 ppm (reflectorless > 500m), standard
Atmospherics corrections	N/A	N/A
Measuring time	1 – 5s / measurement	12s max (Reflectorless)
Motorized motor speed	115° / s	45° / s
Weight	5.15kg (instrument)	4.8 – 5.5 kg

3.4 Test Designs

In this chapter I will outline the three test designs completed for the fulfillment of this project. Test design one comprised of a relatively simply designed test to assess the basic principles, concept and analysis of the instrument for time, accuracy and processing. Test design two comprised of scanning a simulated stockpile for the analysis and representation of the data. Test design three consisted of a more in depth scan of surveying related applications like building encroachments and how reflectorless technology can be used to measure and represent encroachments. This chapter will cover all relative information about these designs and also the field and office procedures that were used to perform them.

3.5 Controlled Surface Scan

Test design one was a basic replication of a field survey scan of a chosen feature. I have chosen to perform a simple test to gain an understanding of the instruments and portray simple results and conclusions to my readers. This test was performed under controlled conditions, with both instruments scanning over a dry wall surface and then a water spray surface. This allowed for easy analysis between the instruments for accuracy, time and conditions. It also allowed me to evaluate the user friendliness of both instruments.

Test one was carried out within the University of Southern Queensland (USQ) grounds in room Z125. The testing surface was marked for permanency in case of data failure or further and future testing. The test site was monitored under a room temperature of 20 degrees Celsius and controlled conditions. Attention was made to the testing wall as not all walls are exactly flat or when pointing the instrument to the same location (see figure 3.3). This will cause small insignificant errors (less than 2mm difference).

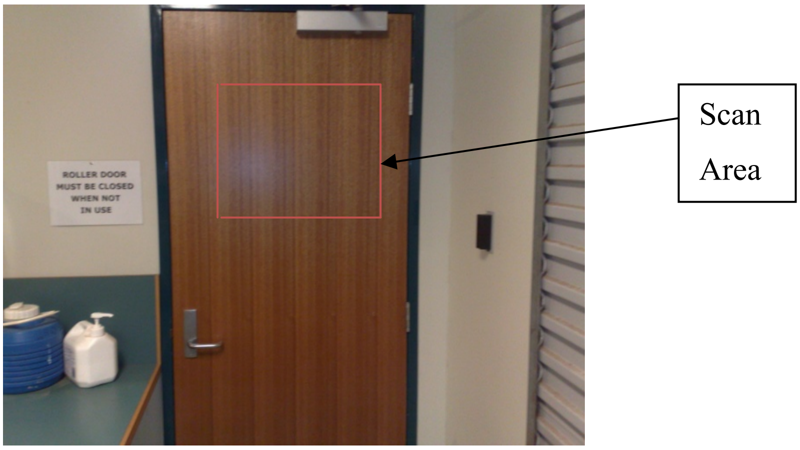

Figure 3.3: Controlled Surface Scan Area.

3.5.1 Data Acquisition

The area scanned for test design one is approximately a 0.500m by 0.500m squared surface. This surface was scanned with both instruments at 0.050mm intervals both horizontally and vertically. For this exercise there was an arbitrary coordinate system set with an arbitrary back sight (BS) set for the purpose of testing.

3.5.2 Field Procedures

Testing procedures will be the same for both instruments where the instruments will be similar except for the instruments software and display.

- After gathering all available equipment, one instrument is setup on the pillar and an arbitrary BS set and coordinates given.
- After setup is completed, continue into the scanning software found for the Leica instrument (Reference line) and the Trimble S6 (Surface scan).
- The scanning software will ask for the type of scan, parameters to be set and the spacing interval. After all parameters have been entered, the scan will initiate.
- The display screen will show how many points have been recorded and how many have not. It also displays an estimated time for the completion of the scan.
- Once the scan is completed all of the data is then stored within the total station on a memory card for extraction to a computer.
- Follow these steps for both instruments and repeat the scan on both a dry wall and a water spray surface. These steps may vary a little depending on the instrument used as there will be slight differences in display modes and the naming of applications.

3.5.3 Office Procedures

Once testing was completed, the data was extracted from both instruments into a computer. The data was then imported into Terramodel where a report was conducted on the points measured. From here the points were imported into Microsoft Excel. The data was arranged and a visual basic macro was applied to the data. This macro works by calculating number of input points N, averages, A matrix, inverse A matrix and the minimum and maximum departures from the best fit plane. These minimum and maximum departures are the distance from the plane to each point also known as the normals. Refer to figure 3.4 and 3.5.

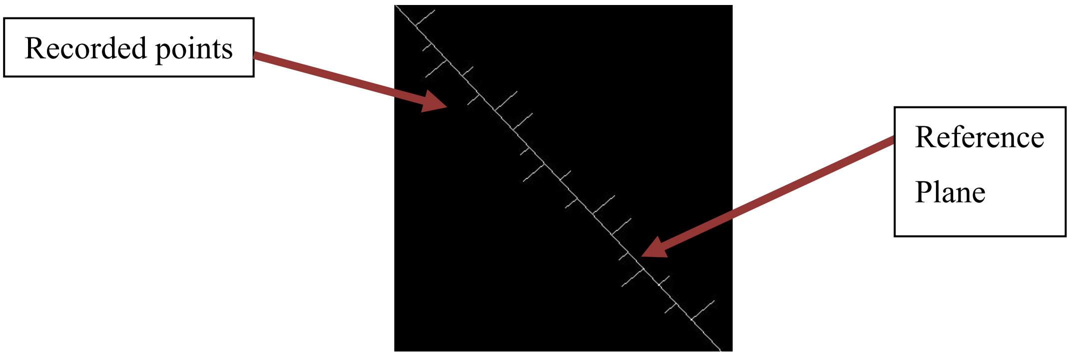

Figure 3.4: Surface Scan Errors

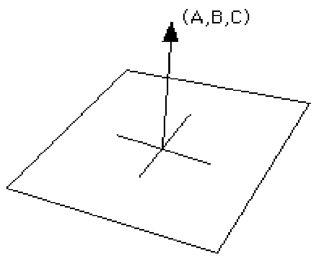

Figure 3.5: Normal's to Plane, Surface Scan
Source: (Bourke 1986)

3.6 Volume Scanning

Many issues in the present day are about health and safety as surveyors in mines or other volumetric areas are not allowed in high places with loose rocks, materials or hazardous situations. From this a potential problem arises, this being the safe gathering of points on a stock pile or high wall. The points need to be gathered but a person must not vantage onto the potential risk areas. Test design two will provide people in this industry the opportunity to acquire some further knowledge and limitations that total station laser scanning and reflectorless measurement can have on the gathering of volumes of stockpiles.

Test site two is situated near the front entrance of the University of Southern Queensland grounds. The scan was performed over a section of raised land used as a retaining wall for water runoff. This section of land is covered by grass and is half situated under tree cover. The site was marked out so repeatability of both instruments could be achieved (See Figure 3.6).

Figure 3.6: Volumetric Test, Simulated Stockpile.

3.6.1 Data Acquisition

Due to software difficulties scanning was not able to be performed with the Leica 1205R. Instead reflectorless measurements were taken along the mound at my discretion over the simulated stockpile for comparisons. The area scanned for test design two is approximately one and a half metres high from natural surface, ten metres wide and ten metres long. This surface was scanned with the Trimble S6 at 0.400mm interval both horizontally and vertically. For this exercise there was an arbitrary coordinate system set with an arbitrary back sight (BS) set for the purpose of testing.

3.6.2 Field Procedures

Testing procedures for the Trimble S6 and Leica 1205R differ slightly due to the software and display. As I stated the Trimble S6 performed a surface scan while the Leica 1205R measured points at my discretion.

- After gathering all available equipment, setup the S6 and then the Leica 1205R and set an arbitrary BS and coordinates.
- After setup is completed, continue into the scanning software for the Trimble S6 (Surface scan) and for the Leica 1205R (Measure topo).
- The scanning software will ask for the type of scan, parameters to be set and the spacing interval. After all parameters have been entered, the scan will initiate. For the Leica 1205R, reflectorless measurements were taken over the mound at my discretion. This was conducted in the data pickup application (used for detail surveys).
- The display screen will show how many points have been recorded, how many have not and it also displays an estimated time for the completion of the scan (Trimble S6 only).
- Once the scan is completed all data is then stored within the total station on a memory card for extraction to a computer.
- Follow these procedures for both sides of the mound as two setups will be needed to acquire all the required information.

3.6.3 Office Procedures

After testing is complete, the data is extracted from the instrument onto a computer using Trimble's data transfer or Leica transfer software. The data was then imported into Terramodel where basic analysis is performed. Data is separated between the base points and points measured on the mound. A DTM is created over both sets of points. A function in Terramodel called earthwork was then used to overlay the DTM from the mound onto the base DTM where an area and volume can be calculated. This process was completed with 100% of points, 75% of points, 50% of points and 25% of points.

3.7 Building Encroachment

Test design three involved simulating a building encroachment situation. This would test the more advanced effects of the laser on oblique angles, building corners, non-reflective surfaces, processing of multiple planes and visual representation. With the use of three dimensional software I was able to fit planes to the data, therefore producing a three dimensional model of the encroachment. The theory was to calculate volumes and distances at any location on the model by the use of planes. However some problems were encountered. This design tested the more in depth measuring of surveying related applications like a building encroachment and how reflectorless technology can be used to measure and represent an encroachment.

Test site three is situated on the southern side of Clive Berghofer Recreation Centre, south of the University of Southern Queensland grounds. The section of building chosen includes guttering & fascias, a rough brick material, oblique corners and edging. For the purpose of testing, marks were placed on either side of the building to represent the cadastral boundaries of an allotment (See Figure 3.7).

Figure 3.7: Volumetric Test, Building Encroachment.

3.7.1 Data Acquisition

The building feature measured is approximately three metres high and ten metres long. The surface was measured using reflectorless technology with both instruments. The measurements were recorded within the instruments for extraction and analysis. For this exercise there was an arbitrary coordinate system set with an arbitrary backsight (BS) set for the purpose of testing.

3.7.2 Field Procedures

Testing procedures will be the same for both instruments where the instruments will be similar except for the instruments software and display.

- After gathering all available equipment, one instrument is setup on the tripod, a job file is started and an arbitrary BS set and coordinates given.
- After setup is completed, continue into the 'Measure topo' software for both the Leica 1205R and Trimble S6 and choose reflectorless as the mode of measurement.
- Six points were taken on each face of the wall and gutters. Two boundary points were also located and a number of natural surface points.
- Once all features have been recorded and stored, they can be extracted from the memory card onto a computer.
- Follow these procedures for both instruments. These steps may vary a little depending on the instrument used as there will be a slight difference in display modes and naming of applications.

3.7.3 Office Procedures

After testing is complete, the data is extracted from both instruments onto a computer. The data was then imported into Terramodel where it is exported into the Leica Cyclone software. From Cyclone some basic interpretation and analysis of the data was performed using the basic editing tools. I was then able to fit a plane to the data collected by using the points on each face of the wall, natural surface and eaves.

Further interrogation of the data was conducted to analyse some results from using the planes to measure distances and not discrete points. Further analysis was also conducted using Terramodel to see if 2D based software could produce similar results. The chainage and offset report was used to analyse the offsets from the cadastral boundary to the encroaching building face.

3.8 Summary: Chapter 3

In summary this chapter discussed the testing sites, data acquisition and also the office and field procedures for each of my test designs. To achieve an accurate comparison between instruments each type of test had to be set on the same coordinate system. It also allowed the general surveyor to gain an understanding of what limitations his or her equipment may offer. The methodology of these three test designs are a replication of my actual procedures and methods used while testing. The following chapter will discuss the results gathered from this methodology.

Chapter 4 – Results and Analysis

4.1 Introduction

The objective of this chapter is to present the results from all test designs undertaken in the methodology. The methodology chapter discussed the appropriate procedures for all test designs and the comparisons between both instruments. The results from the tests include the comparisons between the Trimble S6 and Leica 1205R over various test designs. Each test design compared the instruments for both accuracy and performance. The results will include the data recorded and a short paragraph explaining the results obtained.

4.2 Controlled Surface Scan

The first test was the controlled surface scan which tested the instruments for performance and measuring error. The figure below is a mesh model representing the best fit plane over the points gathered by the instruments. From this mesh model the normal's for each point were calculated from the best fit plane to each data point. This was conducted for both instruments and conditions, producing an error which is the measuring error difference from the plane. Refer to table 4.1 for results.

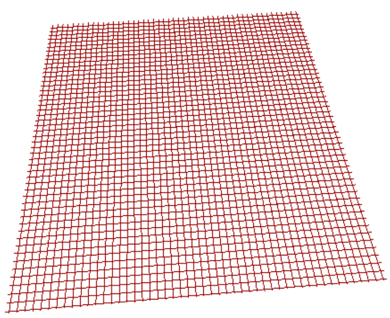

Figure 4.1: Controlled Surface Scan, Best Fit Plane of the data.

4.2.1 Results

Table 4.1: Comparison between instruments.

Instrument	Trimble S6		Leica 1205R	
Surface	Dry Wall	Wet Wall	Dry Wall	Wet Wall
Temperature	20°	20°	20°	20°
Completion Time	4:42	5:32	5:03	5:30
Points collected	124	124	109	109
1 point / second	1/2.1	1/2.6	1/2.7	1/2.9
Mean (m)	0.00037	0.00035	0.00041	0.00035
Standard Deviation (m)	0.00027	0.00026	0.00027	0.00025
% error, (0.250 area)	> 1%	> 1%	> 1%	> 1%

4.2.2 Analysis

The results concluded what was expected from the data gathered. The mean deviation from the plane averaged 0.38 of a millimetre. As the standard deviation was 0.27 of a millimetre difference from the mean. The percentage error calculated to less than a percent over the area. These calculations were performed using a least squares macro using Microsoft Excel. The macro was checked by using the long hand method of least squares which returned the same results. An interesting observation was the points collected per second increased as the scanning conditions went from a dry surface to a wet surface; however the accuracy remained the same. I found the processing time very quick and easy with both instruments.

4.3 Volumetric Scan

4.3.1 Results

Preliminary setup for the volumetric test site established the ground marks and coordinate system for each station. Station 1 was given arbitrary coordinates and reduced level (RL) while station 2 coordinates were calculated and a level run was performed between the two stations.

Figure 4.2 represents the raw data taken by the Trimble S6 of the scanned simulated stockpile. From this figure we can see the outline of the base which was used for both sets of data to accurately compare them. The base points were manually located and strung to form our “cookie cutter”. Two DTM’s were performed over the base data and the data obtained within the base (stockpile). Then the base DTM was taken away from the stockpile DTM to calculate a volume. From this, data was omitted and analysis of the results is shown in tables 4.2 to 4.5.

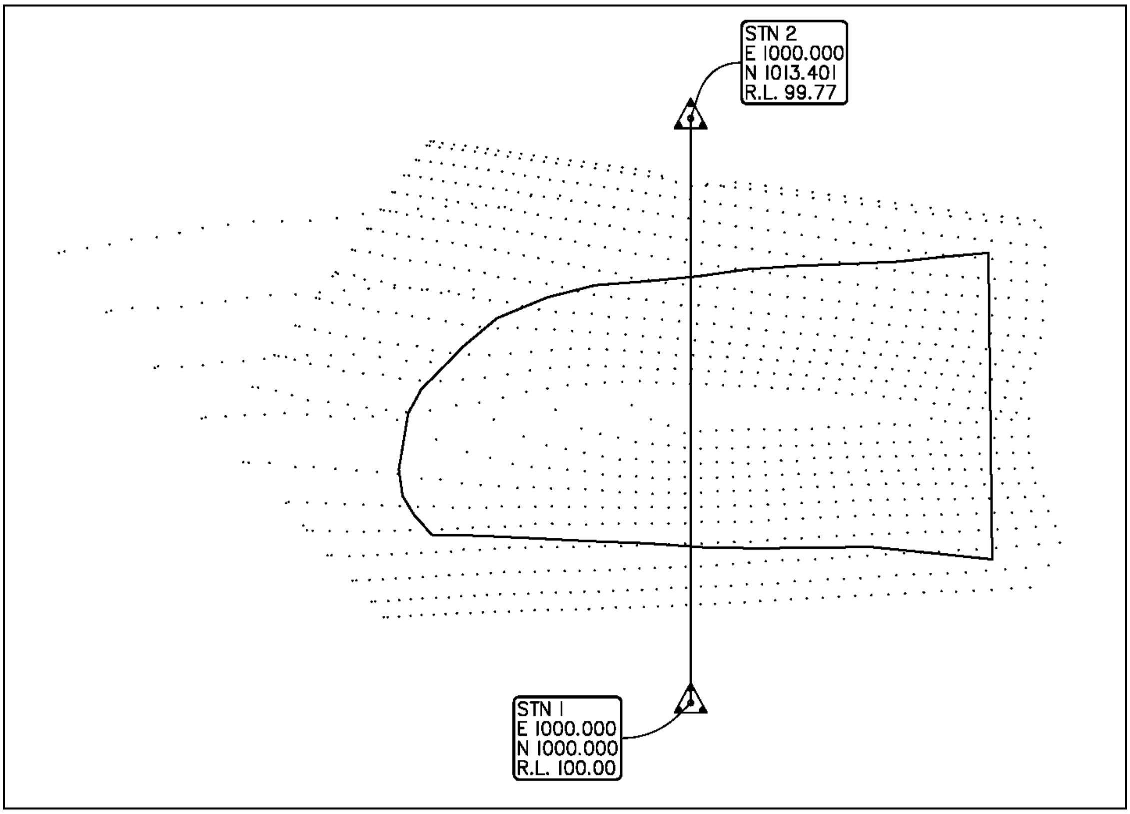

Figure 4.2: Volumetric Test, Raw data Trimble S6, Terramodel.

From this raw data I was able to model and represent the simulated stockpile scanned by both instruments. The models were obtained from Terramodel using the modelling function. Refer to figure 4.3 and 4.4.

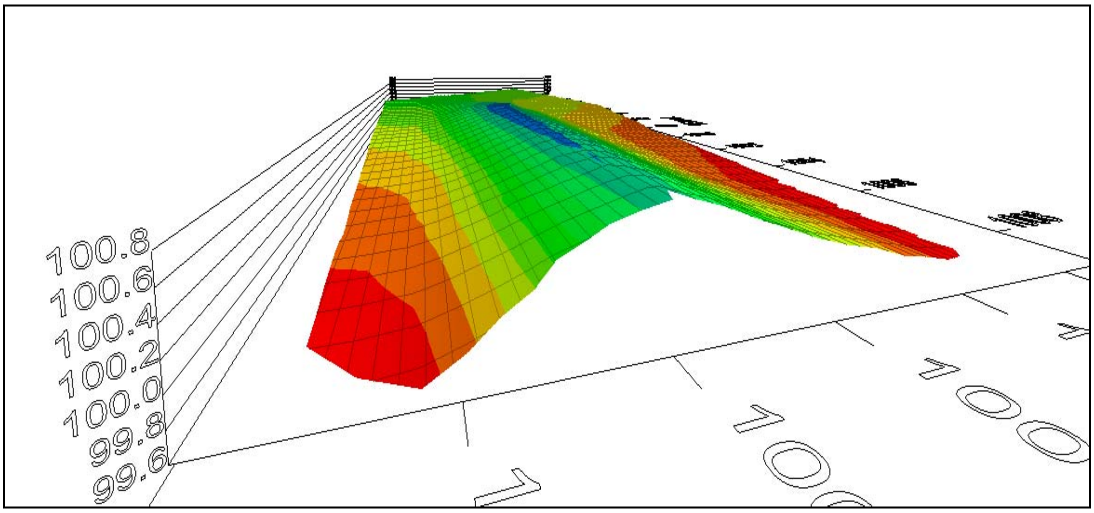

Figure 4.3: Volumetric Test, volume model Trimble S6 #1, Terramodel.

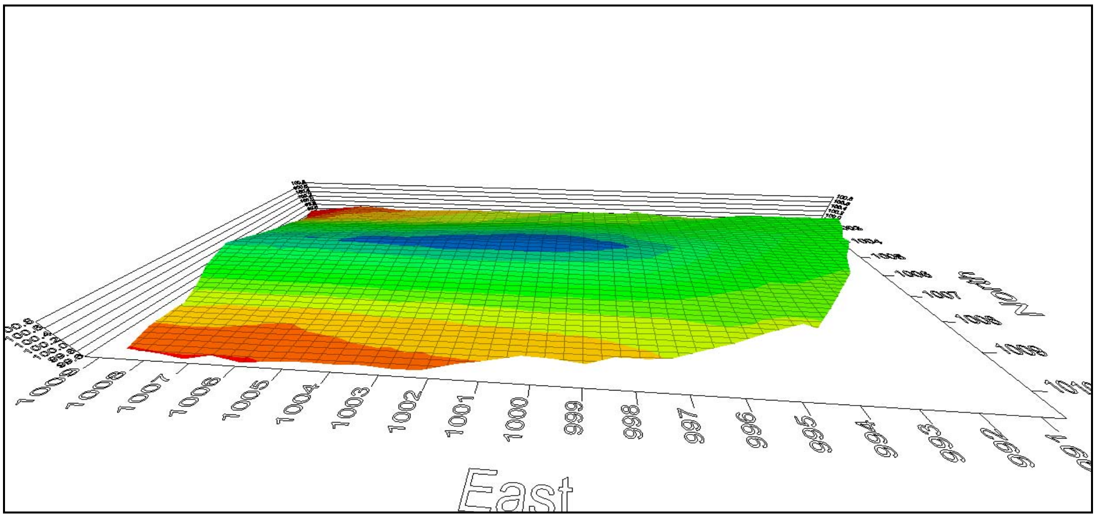

Figure 4.4: Volumetric Test, volume model Trimble S6 #2, Terramodel.

Table 4.2: Comparison between instruments, 100% of data.

Instrument	**Leica**	**Trimble S6**
Surface	Simulated Stockpile	Simulated Stockpile
Temperature	20°	20°
Completion Time	N/A	3.5 seconds/point
Points Collected	171 (mound), 29 (base)	171 (mound), 29 (base)
Area (m²)	83.90	83.90
Volume (m³)	22.59	22.59

The above table represents the results of the volumetric scan for both instruments. As explained above, the base area of 83.90m² will be the same for each instrument because the same base data was used for both. A surprising result found the two instruments produced the same volume for the simulated stockpile 22.59m³. For the purpose of testing I will assume this volume is correct and use it as my base so other calculations can be performed.

Table 4.3: Comparison between instruments, 75% of data.

Instrument	Leica	Trimble S6
Surface	Simulated Stockpile	Simulated Stockpile
Temperature	20°	20°
Completion Time	N/A	3.5 seconds/point
Points Collected	120 (mound), 29 (base)	120 (mound), 29 (base)
Area (m²)	83.90	83.90
Volume (m³)	22.35	22.42
Difference to original (22.59m³)	0.24	0.17
% error (original) of volume	1.06%	0.75%

Table 4.3 represents 75% of the data for both instruments. 25% of points have been removed from both sets to find the optimal scanning interval. For the purposes of testing I have assigned an optimal error value of 5%. This value is the maximum error for each instrument while removing points from the data sets. The error percentage is calculated by the difference between each data set (75%, 50% and 25%) minus the original volume (22.59m³) divided by the original volume again. This error percentage represents the change in volume as a percentage. Our results show we get 1.06% error for the Leica and 0.75% error for the Trimble S6. The volume difference equalled 0.07 metres between instruments. As our results are still under the 5% error we can decrease the amount of point's captured while increasing the scanning interval. Refer below to 50% of data.

Table 4.4: Comparison between instruments, 50% of data.

Instrument	Leica	Trimble S6
Surface	Simulated Stockpile	Simulated Stockpile
Temperature	20°	20°
Completion Time	N/A	3.5 seconds/point
Points Collected	86 (mound), 29 (base)	86 (mound), 29 (base)
Area (m²)	83.90	83.90
Volume (m³)	22.01	22.33
Difference to original (22.59m³)	0.58	0.26
% error (original) of volume	2.57%	1.15%

Table 4.4 represents 50% of the data for both instruments. A further 25% of points have been removed from both sets to find the optimal scanning interval. By removing half of the original points collected our results show 2.57% error for the Leica and 1.15% error for the Trimble S6. The volume difference for 50% of data equalled 0.32 metres between instruments. These results show a steady increase in error but still remain under the 5% optimal error. Furthermore, we can decrease the amount of points captured while increasing the scanning interval again. Refer below to 25% of data.

Table 4.5: Comparison between instruments, 25% of data.

Instrument	Leica	Trimble S6
Surface	Simulated Stockpile	Simulated Stockpile
Temperature	20°	20°
Completion Time	N/A	3.5 seconds/point
Points Collected	52 (mound), 29 (base)	52 (mound), 29 (base)
Area (m²)	83.90	83.90
Volume (m³)	20.80	21.46
Difference to original (22.59m³)	1.79	1.13
% error (original) of volume	7.92%	5.01%

Table 4.5 represents 25% of the data for both instruments. By removing three quarters of the original points collected our results show 7.92% error for the Leica and 5.01% error for the Trimble S6. With a volume difference equal to 0.66 metres between instruments. By reducing the points collected from 171 to 51 we have exceeded our optimal error of 5%. In conclusion, this shows our optimal scanning interval lies somewhere between 50% and 25% of the data as our evidence shows.

4.3.2 Analysis

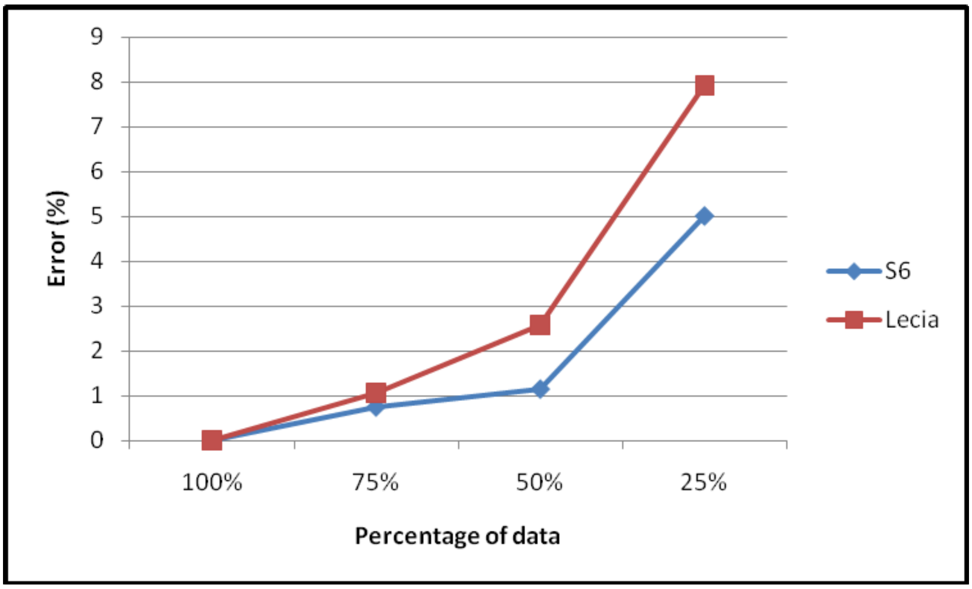

Figure 4.5: Volumetric Test, error percentage for each data set.

Figure 4.5 collaborates the results from the above tables into a graph for easy visual interpretation. As stated above, to find the optimal scanning interval the error percentage should not exceed 5%. From the graph it can be seen that as the data is removed the error progressively increases until a sharp rise from 50 to 25%. This error reaches our optimal error between 50 to 25%. This percentage of the data equates to 1.2 metres scanning interval which is three times that of my starting interval of 0.400 metres. Even though the optimal scanning interval may be 1.2 metres, the break lines (top ridge and base) must be located so the shape is defined. Although the optimal scanning interval for this particular test is established, there is a need for a generic ratio that can be applied to different stockpiles and different circumstances. The calculations below are the expected error for each scanning interval based on the assigned errors and area. I have found the expected error percentage for both 0.4m and 1.2m scanning intervals.

Calculation 1: Original scanning interval (0.4m HA & VA)

Original scanning interval

HA = 0.4

VA = 0.4

Average HT = 0.6

Assigned error for length, breath and height

0.020mm L & B & 0.015mm HT

Volume equation

$V = L^2/2 * HT$

Partial derivative

$dv^2 = (\partial v/\partial l)^2\ dl^2 + (\partial v/\partial ht)^2\ dht^2$

$dv^2 = (l * ht)^2\ 0.02^2 + (l^2/2)^2\ 0.015^2$

$dv^2 = (0.4 * 0.6)^2\ 0.02^2 + (0.4^2/2)^2\ 0.015^2$

$dv^2 = 0.000025$

$dv = 0.0049$

Area = 83.90m²

#Δ's = 83.90 / ($0.4^2/2$)

#Δ's = 1048.75

Propagation of errors

Total error = $\sqrt{1048.75} * dv$

Total error = $\sqrt{1048.75} * 0.0049$

Total error = 0.1587m³ is the error in the whole volume based on these expected errors and a scanning interval of 0.4m

Percentage error

Area = $83.90m^3$

Error = 0.1587 / 83.90

Error = 0.19%

This is the expected error percentage based on my original scanning interval of 0.4m HA and VA. This error is less than one percent, suggesting the scanning interval may be too small. By increasing the scanning interval I can reduce a number of factors and still produce an accurate error percentage.

Calculation 2: Adjusted scanning interval (1.2m HA & VA)

Optimal scanning interval

HA = 1.2

VA = 1.2

Average HT = 0.6

Assigned error for length, breath and height

0.020mm L & B & 0.015mm HT

Volume equation

$V = L^2/2 * HT$

Partial derivative

$dv^2 = (\partial v/\partial l)^2\ dl^2 + (\partial v/\partial ht)^2\ dht^2$

$dv^2 = (l * ht)^2\ 0.02^2 + (l^2/2)^2\ 0.015^2$

$dv^2 = (1.2 * 0.6)^2\ 0.02^2 + (1.2^2/2)^2\ 0.015^2$

$dv^2 = 0.00032$

$dv = 0.018$

Area = $83.90m^2$

$\#\Delta$'s = $83.90 / (1.2^2/2)$

Δ's = 116.53

Propagation of errors

Total error = $\sqrt{116.53} * dv$

Total error = $\sqrt{116.53} * 0.018$

Total error = 1.4483m³ is the error in the whole volume based on these expected errors and a scanning interval of 1.2m

Percentage error

Area = 83.90m³

Error = 1.4483 / 83.90

Error = 1.73%

By increasing the scanning interval to 1.2m HA and VA the error has increased to just below 2%. Based on this adjusted scanning interval the error percentage is still small but has increased significantly compared to the original of less than 1%.

4.4 Encroachment Testing

The encroachment test was conducted to establish correct measuring procedures, reflectorless limitation and if 3D models are better than the 2D plans that are currently used to portray encroachments. Once again a preliminary setup of the encroachment test site established the ground marks and coordinate system for each station. Station 1 was given arbitrary coordinates and RL while station 2 coordinates were calculated and a level run was performed between the two stations.

4.4.1 Results

Measurements were taken on all faces of the building, natural surface and two marks on the ground representing the cadastral boundary. Figure 4.6 represents a 2D model of the data. Traditionally this is how the data is represented and displayed. As this figure is only 2D there is actually three slightly different points at each section of the wall. This is used to represent the vertical orientation of the wall. I have done this because the wall might be leaning or bowed and by taking points at the bottom, middle and towards the top I can model the true vertical orientation of the wall.

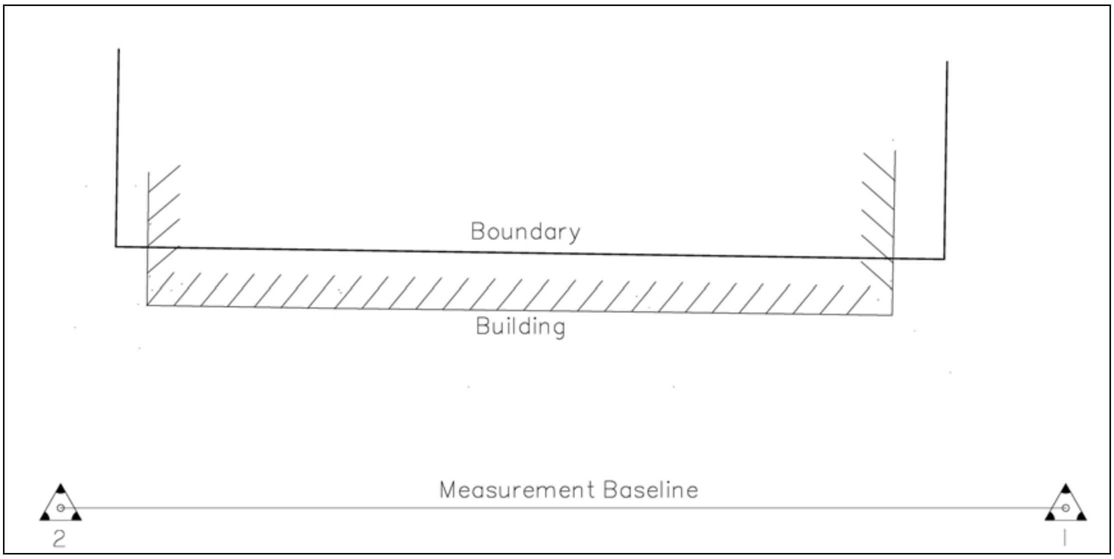

Figure 4.6: Encroachment Test, 2D representation of the encroachment test.

4.4.2 Analysis

From this data I was able to create a 3D model using 3D software like Cyclone. To make the model I best fitted planes to define the building, natural surface and the cadastral boundary producing a 3D model of the encroachment. Figure 4.7 and 4.8 below represents the raw data used to create a 3D model.

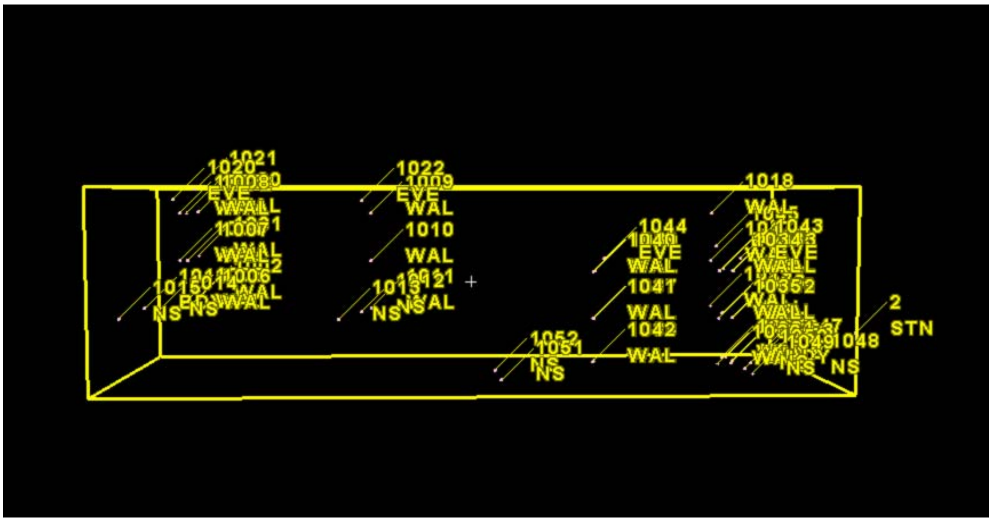

Figure 4.7: Encroachment Test, raw data in Cyclone #1.

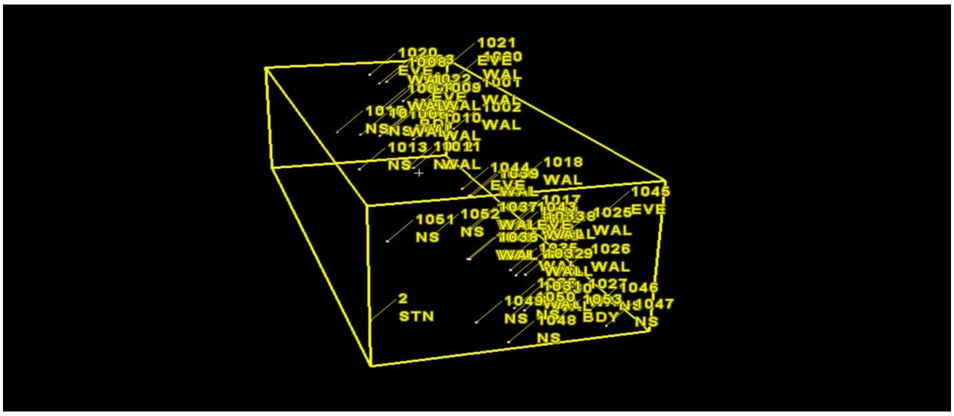

Figure 4.8: Encroachment Test, raw data in Cyclone #2.

Figure 4.9 represents how planes can be used to show the points gathered. The model shows the green plane used to represent the cadastral boundary while the other planes in grey colour represent the building encroachment. Analysis of the planes proved to be difficult as the software would not allow me to perform calculations from plane to plane. This software has the potential to analyse any location on the model to find a distance, area, volume or even the sinuosity of an object.

Due to the 3D modeling capabilities of Leica Cyclone and my inexperience in the software I was unable to gather any measurements. Measuring from point to point is relativity simple and does not require a 3D model. However, for this test my objective was to measure information from one plane to another.

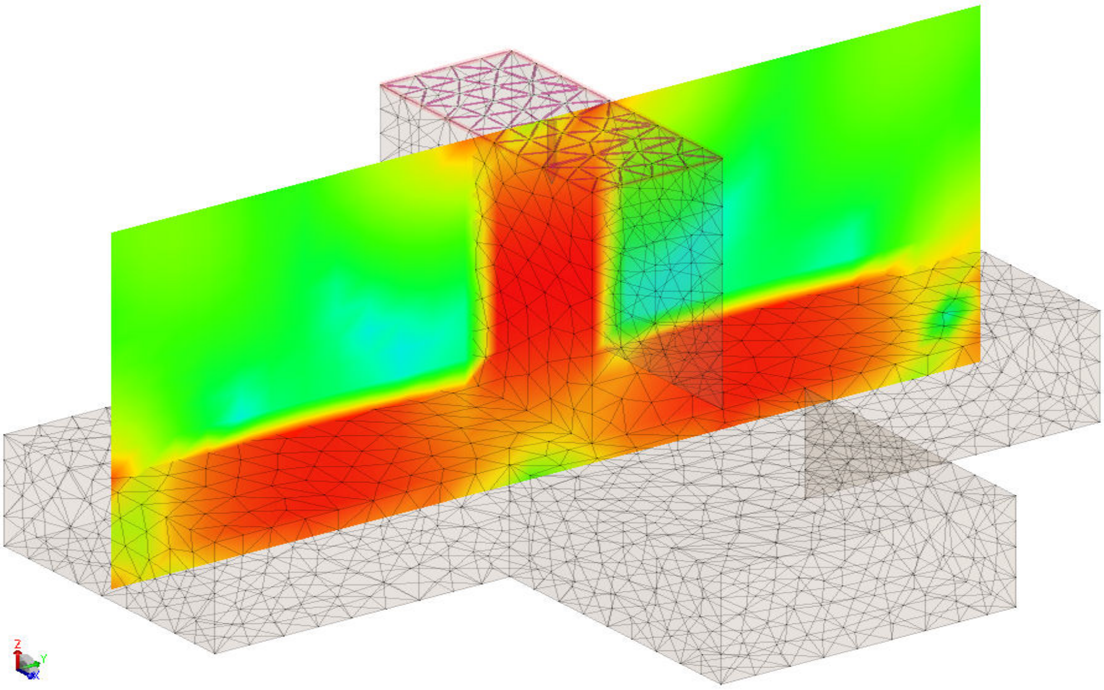

Figure 4.9: Encroachment Test, 3D representation of the encroachment test.

After further discussions with my supervisor we thought it would be good to conduct some additional research into the capabilities of Terramodel. After analysing the data I was able to produce a report showing the chainage and offset from the cadastral boundary to the points on the wall, eaves and natural surface. Below is a section of that report, which shows the chainage and offset distance from the alignment of the cadastral boundary to each point. For the full report refer to appendix H - chainage and offset report.

```
                                ALIGNMENT REPORT
Alignment Name: Free Pts

Point Number      Description      Chainage     Easting      Northing
Elevation         Offset
----------------------------------------------------------------------
-----------

    1004          WAL                2.658      996.670      1004.249
101.389           0.009
    1007          WAL                3.093      996.425      1003.906
101.391           0.004
    1008          WAL                7.681      996.422      1003.909
102.591           4.588
    1011          WAL                8.009      991.829      1003.973
100.190           0.322
    1012          NS                16.916       992.071     1003.760
100.101           8.908
```

Figure 4.10: Encroachment Test, Chainage and Offset Report Terramodel.

4.4 Summary: Chapter 4

In summary this chapter has collectively included all results from each of the three test designs. The controlled surface scan produced as expected results and showed the capabilities of the scanning function. The volumetric test also showed how it can provide surveyors with a useful tool in real scenario surveying. From the results an optimal scanning interval was established for my scan and calculations of the expected errors were performed. Lastly, the encroachment test also showed how reflectorless technology may be used to remotely sense data that is inaccessible and how 3D models may be used to represent spatial information.

Chapter 5 – Discussion

5.1 Introduction

This chapter will discuss the results found during the test design stage. I will discuss some important features found during the designs and the correct methods for conducting them. There will also be discussion of some results found by other students that performed more in depth testing on some sections of my designs.

5.2 Discussion

At the start of this year I was not aware that total stations had integrated laser scanning capabilities into their instruments. I was aware that reflectorless technology was relativity new and the limitations of this technology have not been fully publicised. Throughout the progression of this project I have realised the full potential these instruments have. Their usefulness and applications in the surveying industry is advantageous and notable.

5.2.1 Controlled Surface Scan

The controlled surface scan was a basic test to analyse and compare both instruments against one another and the manufacturer's specifications. From my testing the results that were found was what was to be expected. The errors were very small and insignificant (0.00027m). The manufacturers claim a 2mm + 2ppm error for distances measured less than 500 metres. The object I measured to was 5 metres away from the instrument, so it was expected that there would be an error in the measuring device and that error would be very small over this distance. Further comparison could have been done to test the error at different intervals further away from the object. After listening to another student's presentation he concluded that the error did increase and that there was beam divergence the further away he got. An issue I had concerns with was the laser dot in accordance with the optical cross hairs in the total station. After talking to another student doing a similar project it was realised that he had came to the same conclusion which was that they were not in accordance with one another. Care must be taken when measuring to features to always try and use the cross hairs within the optical devices as this has be calibrated (in most cases).

The next comparison was between both instruments and as expected again there was no difference between each instrument where they produced roughly the same error. From this I could not distinguish between them as they are in error by roughly the same factor. It is important to note that although the instruments are made by different manufacturers, they both have similar characteristics. They are both have magnetic driven systems, have similar specifications and similar capabilities. However, the Trimble S6 uses a pulsed based mode of measurement and the Leica uses a phase based mode of measurement. From my results I cannot distinguish between the modes of measurement as there are no differences in error. Further testing would be required to ascertain this information.

Last was the comparison of both instruments over the different conditions. As expected again there was very small error difference from a dry surface to a wet surface. However one thing I did find different was the change in recording time. The manufacturers specify 3 – 6 seconds a point less than 500 metres. When performing my tests I achieved one point every 2.1 seconds on a dry surface and 2.6 seconds on a wet surface with the Trimble S6. This increase is consistent with both instruments which suggest that water droplets on a walls surface will delay the return signal.

As I was experimenting with the instrument I noticed that they did not reflect from certain objects. These features included a glass panel on a door and a light covering made of rough plastic. I found that there was no return signal when measuring to the light covering which suggests that there was scattering and absorption contributing to this. When the instrument measured to the glass on the door it sounded like a faint signal was being returned as the instrument would beep once compared to no beep for the light covering. The instrument tried to measure this particular point up to 4 times before it disregarded it. Measuring to any feature that affects the EMR is difficult to rely on the results, care must be taken when recording information to features that may alter the signal.

While the error at close distances is small, correct measuring producers must still be used. As discussed in the literature review section 2.5.2, a laser beam may not necessarily be measuring what you are pointing to. The correct procedures for measuring building corners are to measure the faces of the building and intersect them in the office to get the corner. This will eliminate the errors of measuring to external or internal corners. Another important factor to consider when measuring features is the angle of incidence from the instrument to the feature being measured. In my test I was not affected by this as I was perpendicular to my testing object. When conversing with my peers it became apparent that one student tested the affects of angle incidences and found that as the angle became acute there was no reflection from the object. This was due to the acute angle deflecting the laser beam in an opposite direction rather than reflecting back to the instrument.

5.2.2 Volumetric Scan

Workplace Health and Safety stops surveyors from venturing onto unsafe areas whether it be a stockpile, high wall in a mine or high places like a building feature. These issues along with accurately taking measurements can cause problems. Accurately measuring volumes is difficult; this is mostly due to the varying and undulating topology of the surface. This results in an approximated volume based on the measurements taken. Due to laser scanning technology, a surface can be scanned at less than 50mm intervals, producing a high 3D level of detail. From this model a volume can be calculated by taking the scanned surface away from a base level (usually natural surface) which leaves the volume.

So the question is, will taking more points at closer scanning intervals produce a better estimated value than fewer points at larger intervals? From my test I was able to establish this relationship and find the optimal scanning interval that would still produce an accurate value. Accuracy raises another question of how accurate does the volume need to be? Mines have the perspective that accuracy is not an important trait. This is misconceived in some contexts as the monitoring of a wall to find if it will collapse or the volumetric calculation of a material that is exchanged for money is very important and must be accurate.

Over the past 15 years the method of measuring volumes has evolved from recording points with a prism & pole to reflectorless and now laser scanning. Reflectorless has removed the risk of unsafe procedures by remotely sensing points of data from a safe position. In the last ten years laser scanning units have been introduced to surveyors. The laser scanning unit could only perform scans and was very expensive. This system is typically used in the mines as they can afford it and they have the need for gathering a lot of point's inaccessible areas. Technology has now gone one step further and incorporated scanning into total stations. This results in the everyday surveyor still having the ability to perform general surveying applications, however now having the ability to perform scans on a surface.

From the undertaking of the research involved in writing this dissertation I learnt a lot about what the software can do and the correct procedures for performing them. As I have stated previously total station scanning is relatively new and there has been limited testing on this technology. I believe incorporating scanning capabilities into a total station is the way to the future in surveying equipment. The introduction of a scanning function has not altered the physical instrument or internal components. There are no disadvantages by including the scanning function into a total station besides the capabilities of the scanner & drafting software, "but something is better than nothing". Below is a list of the advantages and disadvantages of laser scanning.

Advantages of a total station scanning instrument:

- A single total station instrument is cheaper compared to that of a single laser scanning unit.
- A total station instrument has more capabilities than that of a single laser scanning unit (can still perform traditional traversing etc).
- The data captured is compatible with current surveying software (Terramodel, AutoCAD etc).

- The scanning function is useful for the everyday surveyor that would only perform a limited amount of scans a year.
- Ability to record information that was not accessible before due to safety issues.
- It is a single complete unit, as the external and internal characteristics of the instrument have not changed compared to a scanner which needs a laptop, external battery, etc).
- Requires only one field technician.
- Semi-automated stand alone system (set it up and let it scan).

Disadvantages of a total station scanning instrument:

- The 3D software capabilities are limited.
- Cannot view in real time.
- A laser scanning unit can record up to 50,000 points a second, while a total station records one point every 3 seconds.
- The scanning capabilities are only basic compared to that of a laser scanning unit.

In my opinion the advantages of including a laser scanning function into a total station outweigh the disadvantages. As technology continues to evolve the disadvantages listed above will be refined and tuned which will enhance the technology. Like all technology it will become quicker, the software capabilities will become better and the ability to connect up to a laptop and get real time information will be available within the near distant future.

The main purpose of this test was to scan a simulated stockpile with both instruments to find the optimal scanning interval. Due to some problems with the Leica's scanning software I was unable to perform a scan but instead recorded reflectorless measurements at my discretion. The Trimble S6 performed the scan very well, with no problems and all the points captured. The data processing stage was also very quick and easy as the data was extracted straight into Terramodel where I could investigate it. Besides the fact that I could not perform a scan with the Leica the data processing was straight forward. Once the data was imported into Terramodel I calculated a volume for both sets of data. From this I proceeded to remove 25% of the data and calculated a volume. I continued this formula to find a result for 50% and 75% of the data removed to calculate the percentage of change. Removing 25% and 50% of data only equated to a 1% change with the Trimble and roughly a 3% change with the Leica. A noticeable change occurred when 75% of data was removed where the Trimble went to 5% and the Leica 8%. After discussion with my supervisor we decided that the error would become significant once the data reached 5%. This would be our optimal scanning interval. The initial scanning interval was 0.400m horizontally and 0.400m vertically.

By adopting only 25% of the original data for this test, the scanning interval was three times that of my starting interval. The optimal interval for my particular test was 1.2 metres. It is important to note the break lines, those being the top ridge and base of the feature being scanned. If in my situation I did not gather enough data along these break lines then I would not be confident that the shape of my stockpile would be truly represented. This would lead to a poorly estimated volume as areas of the stockpile would be generalised because of significant data and not the true shape of the undulating surface.

When comparing the error percentage between both instruments, the Trimble S6 shows the least amount of error deviation compared to the Leica at all three changes (75%, 50% and 25%). Additional analysis of the instruments led me to investigate the apparent variations of points over the simulated stockpile. The Trimble S6 data pattern is uniform and evenly spread across most of the stockpile. This is expected as the instrument controls the pointing of the instrument after the user has defined the parameters as compared to the Leica where reflectorless measurements were taken at my discretion over the simulated stockpile. Currently this is standard practice as most surveying companies gather points the traditional way by using a pole and prism which see's each point reliant on the technician's discretion. Figure 4.5 would suggest a uniform and machine guided pointing will produce a more accurate measurement. However, this may not be the case. When performing a scan the instrument will only record points on its grid section. The instrument will not detect sudden variations in the surface, whereas by using the traditional method the field technician can locate the sudden variations. This all comes back down to the scanning interval. A larger scanning interval will generalise the surface more and miss certain information if the interval is too large. Compared to small scanning intervals this will better estimate the surface as it will locate more points and produce a more accurate model of the surface, essentially producing more accurate results. But will measuring at smaller intervals produce a more accurate answer than larger intervals and greater generalization of the surface? Figure 4.5 suggests that a smaller scanning interval does produce more accurate results. This is because as the data was removed the error increased. From this figure it also suggests that the uniform scanning pattern of the Trimble S6 also produced more accurate results than randomly locating points with the Leica. Because the S6 scan is uniform, at set gridlines and small scanning interval, the level of detail at critical locations is captured. By having a uniform scan over the simulated stockpile the error was reduced compared to that of randomly locating points at my discretion. This strengthened the idea that scanning will produce a more accurate answer.

Manual calculations were carried out to find the expected error for 0.4m and 1.2m scanning intervals. These calculations were done by using partial derivative and propagation of errors methods. The results found for 0.4m scanning interval the error equated to less than 1% for the total area. By increasing the scanning interval to 1.2m the error was just under 2% for the total area. These errors are based on the whole volume and are influenced by the assigned errors and scanning interval.

As reflectorless does not require anything to reflect, its measurements are taken to the first thing that the laser comes in contact with, which in this case is the grass. But when recording information, traditionally we use a prism and pole and when placing the pole into the ground it would be 30 to 60mm under the surface of the grass. This raises another problem of what is the surface we are trying to measure. Is it just below the dirt, dirt level or grass level? In most cases this difference will not matter, but surveyors need to be mindful of what incident energy is reflecting from.

In summary as the data was extracted the error percentage increased. I established that this error percentage should not exceed 5% as the error would then become significant. By removing data I could continue to calculate my error percentage until I reached the 5%. This percentage exceeded my optimal error between 50 and 25% of the data. This equated to 3 times my starting interval of 0.4m to 1.2m. By using a 1.2m scanning interval on my initial scan I could have reduced my scanning time, data processing, storage and still maintained an accurate volume.

5.2.3 Encroachment Testing

The encroachment testing was conducted to establish correct measuring procedures, reflectorless limitations, capabilities of the software and if a 3D model of the encroachment is better than a 2D plan which are currently used to portray encroachments. The design had to replicate a building encroachment situation. With the use of both instruments, reflectorless measurements were taken to the building walls, eaves, natural surface and two marks representing the cadastral boundary. The aim of this data was to create a 3D model of the encroachment by fitting planes to the points captured. From this model I was expecting to obtain measurements from plane to plane to calculate distances, volumes and areas etc. The second analysis was to use Terramodel to calculate a chainage and offset report from the cadastral boundary to each point on the wall.

Due to some software capabilities and my inexperience in the software I was not able to record any measurement from plane to plane. The theory behind using a 3D model was to use planes instead of discrete points to perform calculations. This would provide better analysis of information anywhere on the model thereby achieving greater accuracy for calculating volumes and distances at any location on the model. After some manipulation with the data structure I was able to import it into the Leica Cyclone software. From this I fitted planes between points and produced a 3D model. However, my analysis had come to a halt as I could not perform my intended calculations. The software would only let me perform measurements from point to point which I can do in a normal software package. On a positive note, the 3D software did make it easier to visualise the model and select points.

Figure 4.9 shows how planes can be used to show the shape of a building and the cadastral boundary. This model provides a greater level of detail and information compared to traditional 2D plans that are currently used to represent encroachments. Referring to Appendix E which shows the right hand side of the survey plan where there are two garden sheds encroaching. These are shown as a single black line over the boundary with an annotation of 0.9 over. In 4.9 we can see precisely where the cadastral boundary slices through the building. With this model the ability to annotate these lines and planes to include areas, volumes and distances would be useful. As modeling software continues to evolve I expect calculations from plane to plane and other functions will become available.

Looking at a more complex encroachment like the Gabba stadium in Brisbane there are beams, braces and structural features all throughout the encroachment. Because the encroachment is not fully enclosed like my example above, the impression of the encroachment may be misunderstood to be that the whole area/volume under this is encroaching. But in fact only a small volume of features are encroaching. In this situation a single 2D plan does not do justice to fully show the encroachment. Only showing the furtherest extended structural edging may be ok to show the extent but should provide more information. If there was a 3D scanned drawing of the complex encroachment then a whole range of analysis may be performed like calculations of clearances, structural design, improvements and from the surveying side the encroachment itself represented in 3D. When compared to the 2D representation of the encroachment we could not acquire this information. This method of representation also raises problems of software capabilities, failure to produce a hard copy plan and the amount of detail actually required for the encroachment.

The second method of analysis was producing a report showing the chainages and offsets from the cadastral boundary to each feature using Terramodel. The process was to assign an alignment to the cadastral boundary. From this alignment a report was done which calculated the chainage along the alignment from the start and the offset from my alignments to each feature. This method worked well and the report was very quick. But in the situation where the building encroachment completely obstructs a clear view from one boundary corner to the other, there is a problem of knowing if you are on that alignment to measure the offset. When creating this alignment there is no vertical component. I recorded three measurements at different heights above each other to show the vertical orientation. This method of interpolating the chainage and offset is difficult to measure in the field. This method may be useful not to produce a report but to transfer data. Instead of producing a report, the information can be exported as a text file. The text file would contain point numbers, description, chainage, offsets and elevation. Form this text file the data can imported into Terramodel, AutoCAD or a hardcopy plan. This may be an alternative approach for lodging encroachment information.

Finally, I would like to mention the electronic lodgment of survey related information. Currently, most encroachments are represented on 2D plans refer to appendix I. Most encroachments are represented by the most extended feature encroaching on the neighbouring land whether it is the crown or private land. In the case that the encroachment was quite complex and a greater detail of information is required then how is this to be displayed on a 2D plan? At the moment there is no provision for lodging electronic plans. Currently in progress is a system of electronic lodgment of surveying data (survey plans). Electronic lodgment of survey information may enhance the level of information provided to clients, developers and other surveyors. In the case mentioned above about the Gabba stadium in Brisbane, an electronic lodgment of the survey scan or reflectorless measurements would provide people with more information. The plan may be sent electronically at a fee to the person requesting the information where they can use a 3D modeling software to interrogate and query the information. This would save costs and time because the current 2D plan does not show any extra information and a 3D plan can include information about the beams, braces, size and shape of features which can be stored on a single electronic drawing.

5.3 Summary: Chapter 5

This chapter covered an in-depth discussion of all three test deigns, their results, performance and conclusions. Both instruments performed to the manufacturers specification over all three tests. This chapter also covered some conclusions sought from other peers about what they have found during their testing. The discussions not only spoke about the advantages but more importantly the disadvantages of the instruments, software and their abilities. The next chapter will discuss my recommendations and a final conclusion about the equipment and objectives for this project.

Chapter 6 – Recommendations & Conclusion

6.1 Introduction

This chapter will outline some recommendations that may be of assistance to users in regards to total station laser scanning and the establishment of guidelines that industry companies can develop. To conclude there will be a summary of the final outcomes of this project and a statement of whether I have achieved the objectives set at the commencement of this project.

6.2 Recommendations

The Leica 1205R and the Trimble S6 have proven to be very useful tools in surveying applications. Both instruments have reflectorless technology and laser scanning functions which have satisfied the three tests that were conducted. However, there are a number of key features that I would recommend to the manufacturers of these instruments and also to users. They are:

Polygon scan feature: Both instruments have a number of scan functions built into the instrument that allows the user to choose the type of scan they want. Some include rectangle scan and offset scan. The problems with these applications are that they mainly cater for scanning surfaces that are parallel and perpendicular because that is how the scan area is defined. Most stockpiles or mounds of dirt are in the shape of a bell shaped curve or an upside down parabola. So instead of defining a rectangle scan area over the stockpile, the user could identify the scan area by locating a number of points along the break lines of the feature and the scan would be contained within this area. By doing this, a lot of factors may be reduced including the amount of point data captured, scan time, storage and processing time.

Inefficient measuring of non-reflective points: On average it takes a total station 3.5 seconds to record a point. When measuring a non-reflective feature the instrument will try to record the point up to 4 times before it disregards it and moves to the next one. When I compared a total station scanning instrument and a laser scanning unit I found that the laser scanning unit will disregard points if they do not reflect the first time whereas a total station instrument continues to record the point. This leads to inefficient measuring of non-reflective points, resulting in time loss. I recommend including a feature that specifies the number a retries a single point may have if the point is non-reflective.

Establish guidelines on optimal scanning intervals and expected errors: Most surveying applications like detail surveys rely on the user's discretion on optimal contour intervals and the like. I believe that establishing guidelines on optimal scanning intervals of different features, shapes and materials would be of great benefit. This may be utilised as a guide for users because I found that I chose either a higher spacing interval or lower spacing interval than that of the optimal spacing interval. This resulted in me recording too much data or not enough data. Guidelines also need to be established on expected errors for the scanning of grain, soil, rock and coal etc. Additional information about different material densities can also be included and applied in the calculation stage to gather a better approximation of volume.

Encroachments: Currently in Queensland there is no provision for electronic lodgment of surveying information (survey plans, volumetric plans etc). I believe this is currently in the process of changing to electronic lodgment of surveying data. By introducing this new method of lodgment other related information like a 3D model scans of an encroachment may be attached to the survey plan and lodged as one. This method would be most beneficial in mining situations where a standard can be established and information stored about the workings of mines. I personally believe this is the way of the future as technology is continually evolving and an increasing amount of information is transferred electronically via computers and the internet.

6.2.1 Further Research

This project has covered three areas of testing and analysis involved with reflectorless technology and laser scanning capabilities. They are controlled surface scan testing, volumetric testing and encroachment testing. Further research can be conducted over the three tests designs within this project.

More extensive research may be carried out on my first test, the controlled surface scan, by measuring and analysing the effects of a wide range of colours, surfaces (rough or smooth), water, range and materials. As I only touched the basis on most of these areas, further research would be useful for determining errors in different applications.

The calculations of volumes are never 100% correct due to the irregularities within materials. Most volumetric surveying scans are approximated based on the area between points and not a true model of the varying area. Most of the materials scanned will contain air pockets or gaps between the materials which when scanned will over estimate the volume. This is due to the amount of spacing or area between materials and will also depend on the material measured. For example, a rock may have bigger gaps or spacing compared to a grain material. Therefore, there is the need for further research into densities of different materials in determining more accurate measuring of volumetric features.

My final recommendation is to further the research into the requirements of a surveyor in an encroachment situation. Research the requirements of accuracy, information required and the representation of encroachments on survey plans. Particularly the lodgment of electronic encroachment plans and how they may attach to a survey plan and lodged in the titles office.

6.3 Conclusion

The reflectorless capabilities of both instruments performed very well with little difference between the two. However, the scanning capabilities of the Trimble S6 proved to be the better instrument due to its user-friendliness, quick & easy setup of scans and easy processing of data. The Leica 1205R was still a suitable instrument for performing scans but it had a difficult to follow display, naming of applications and took a long time to setup scans.

My supervisor and I set out a number of goals to achieve throughout the fulfillment of the project. I believe I have covered most of the objectives to a satisfactory standard. This dissertation covers the research of existing laser scanning technology, capabilities and specification of both the Trimble S6 and Leica 1205R. It also includes the three test designs which analysed both instruments for speed, accuracy and performance on a range of different applications including a simple point comparison, scans over a simulated stockpile and reflectorless measurement of building features which were performed under different conditions. These tests were analysed according to a range of criteria where the implications and results were discussed with respect to surveying organisations and potential opportunities.

In conclusion, this project compared the laser scanning capabilities and reflectorless limitation of two robotic total stations for various surveying applications. Reflectorless and laser scanning capabilities were tested and the fundamental theory behind the technology was discussed in the literature review. The methods, results and discussions covered the test designs performed and the outcomes of these tests. This conclusion spoke about my recommendations, further research and an overview of my dissertation.

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Appendices

Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Jeffrey Jones

TOPIC: Comparison of robotic total stations for scanning of volumes or structures

SUPERVISORS: Assoc Prof Kevin McDougall

ENROLMENT: ENG 4111 – S1, D, 2009;
ENG 4112 – S2, D, 2009

PROJECT AIM: This project seeks to compare the laser scanning capabilities and reflectorless limitations of two robotic total stations for various surveying applications.

PROGRAMME: **Issue A, 24 March 2009**

1. Research the existing Laser scanning technology, capabilities and specification of both the Trimble S6 and Leica 1205R.
2. Identify a rigorous testing regime (speed, accuracy etc) and range of possible testing applications including mining stock piles, buildings and vegetation.
3. Test the scanning capabilities on various features including coal, grain, structural features (roof heights, floor heights and window frames) and survey control under different conditions.
4. Analyse the outcomes of the test according to a range of criteria.
5. Discuss the implications of the results with respect to surveying organizations and potential opportunities.
6. Write up the dissertation.

As time permits

7. Extend the range of scanning tests and situations.

AGREED: ____________ (Student) ____________ (Supervisor)

Date: 23/3/2009 Date 24/3/2009

Examiner/Co-examiner: ____________ 31/03/09

Appendix B – Trimble S6 Datasheet

TRIMBLE S6 DR300+

PERFORMANCE

Angle measurement	
Accuracy (Standard deviation based on DIN 18723)	2" (0.5 mgon) 3" (1.0 mgon), or 5" (1.5 mgon)
Angle reading (least count)	
Standard	1" (0.1 mgon)
Tracking	2" (0.5 mgon)
Averaged observations	0.1" (0.01 mgon)
Automatic level compensator	
Type	Centered dual-axis
Accuracy	0.5" (0.15 mgon)
Range	±6' (±100 mgon)
Distance measurement	
Accuracy (S. Dev.)	
Prism mode	
Standard	±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm)
Tracking	±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm)
DR mode	
Standard measurement	±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm)
Tracking	±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm)
>300 m (656 ft)	
Standard measurement	±(5 mm + 2 ppm) ±(0.016 ft + 2 ppm)
Measuring time	
Prism mode	
Standard	1.2 s
Tracking	0.4 s
Averaged observations[1]	1.2 s per measurement
DR mode	
Standard	1–5 s
Tracking	0.4 s
Averaged observations[1]	1–5 s per measurement
Range (under standard clear conditions[2,3])	
Prism mode	
1 prism	2500 m (8202 ft)
1 prism Long Range mode	5500 m (18,044 ft) (max. range)
3 prism	3500 m (11,482 ft)
3 prism Long Range mode	5500 m (18,044 ft) (max. range)
Shortest possible range	0.2 m (0.65 ft)
DR mode (typically)	
Kodak Gray Card (18% reflective)[4]	>300 m (984 ft)
Kodak Gray Card (90% reflective)[4]	>800 m (2625 ft)
Concrete	300–400 m (984–1312 ft)
Wood construction	200–400 m (656–1312 ft)
Metal construction	200–250 m (656–820 ft)
Light rock	200–300 m (656–984 ft)
Dark rock	150–200 m (492–656 ft)
Reflective foil 20 mm	800 m (2,625 ft)
Reflective foil 60 mm	1600 m (5,249 ft)
Shortest possible range	2 m (6.56 ft)

EDM SPECIFICATIONS

Light source	Pulsed laserdiode 870 nm, Laser class 1
Laser pointer coaxial (standard)	Laser class 2
Beam divergence	
Horizontal	4 cm/100 m (0.13 ft/328 ft)
Vertical	8 cm/100 m (0.26 ft/328 ft)
Atmospheric correction	–130 ppm to 160 ppm continuously

TRIMBLE S6 HIGH PRECISION EDM WITH DR

PERFORMANCE

Angle measurement	
Accuracy (Standard deviation based on DIN 18723)	1" (0.3 mgon)
Angle reading (least count)	
Standard	1" (0.1 mgon)
Tracking	2" (0.5 mgon)
Averaged observations	0.1" (0.01 mgon)
Automatic level compensator	
Type	Centered dual-axis
Accuracy	0.5" (0.15 mgon)
Range	±6' (±100 mgon)
Distance measurement	
Accuracy (S. Dev.)	
Prism mode	
Standard	±(1 mm + 1 ppm) ±(0.003 ft + 1 ppm)[5]
Tracking	±(5 mm + 2 ppm) ±(0.016 ft + 2 ppm)
DR mode	
Standard measurement	±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm)
Tracking	±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm)
Measuring time	
Prism mode	
Standard	2 s
Tracking	0.4 s
Averaged observations[1]	2 s per measurement
DR mode	
Standard	3–15 s
Tracking	0.4 s
Averaged observations[1]	3–15 s per measurement
Range (under standard clear conditions[2,3])	
Prism mode	
1 prism	3000 m (9,800 ft)
1 prism Long Range mode	5000 m (16,400 ft)
3 prism	5000 m (16,400 ft)
3 prism Long Range mode	7000 m (23,000 ft)
Shortest possible range	1.5 m (4.9 ft)
DR mode (typically)	
Kodak Gray Card (18% reflective)[4]	>120 m (394 ft)
Kodak Gray Card (90% reflective)[4]	>150 m (492 ft)
Concrete	80–150 m (262–492 ft)
Wood construction	80–180 m (262–590 ft)
Metal construction	80–120 m (262–394 ft)
Light rock	80–120 m (262–394 ft)
Dark rock	60–80 m (197–262 ft)
Reflective foil 20 mm	600 m (1,968 ft)
Reflective foil 60 mm	1200 m (3,937 ft)
Shortest possible range	1.5 m (4.9 ft)

EDM SPECIFICATIONS

Light source	Laserdiode 660 nm; Laser class 1 in Prism mode Laser class 2 in DR mode
Laser pointer coaxial (standard)	Laser class 2
Beam divergence Prism mode	
Horizontal	4 cm/100 m (0.13 ft/328 ft)
Vertical	4 cm/100 m (0.13 ft/328 ft)
Beam divergence DR mode	
Horizontal	2 cm/50 m (0.066 ft/164 ft)
Vertical	2 cm/50 m (0.066 ft/164 ft)
Atmospheric correction	–130 ppm to 160 ppm continuously

Appendix C – Leica TPS1200+ Datasheet

Leica TPS1200+
Technical specifications and system features

Models and options

	TC	TCR	TCRM	TCA	TCP	TCRA	TCRP
Angle measurement	•	•	•	•	•	•	•
Distance measurement (IR-Mode)	•	•	•	•	•	•	•
PinPoint reflectorless dist. measurem. (RL-Mode)		•	•			•	•
Motorized			•	•	•	•	•
Automatic Target Recognition (ATR)				•	•	•	•
PowerSearch (PS)					•		•
Guide Light (EGL)	∘	∘	∘	•	•	•	•
Remote Control Unit / RadioHandle	∘	∘	∘	∘	∘	∘	∘
GUS74 Laser Guide				∘		∘	
SmartStation (ATX1230 GG)	∘	∘	∘	∘	∘	∘	∘

• = Standard ∘ = Optional

Angle measurement

		Type 1201+	Type 1202+	Type 1203+	Type 1205+
Accuracy (std.dev., ISO 17123-3)	Hz, V	1" (0.3 mgon)	2" (0.6 mgon)	3" (1 mgon)	5" (1.5 mgon)
	Display resolution:	0.1" (0.1 mgon)	0.1" (0.1 mgon)	0.1" (0.1 mgon)	0.1" (0.1 mgon)
Method	absolute, continuous, diametrical				
Compensator	Working range:	4' (0.07 gon)	4' (0.07 gon)	4' (0.07 gon)	4' (0.07 gon)
	Setting accuracy:	0.5" (0.2 mgon)	0.5" (0.2 mgon)	1.0" (0.3 mgon)	1.5" (0.5 mgon)
	Method:	centralized dual axis compensator			

Distance measurement (IR-Mode)

Range	Round prism (GPR1):	3000 m
(average atmospheric conditions)	360° reflector (GRZ4):	1500 m
	Mini prism (GMP101):	1200 m
	Reflective tape (60 mm x 60mm)	250 m
	Shortest measurable distance:	1.5 m
Accuracy / Measurement time	Standard mode:	1 mm + 1.5 ppm / typ. 2.4 s
(standard deviation, ISO 17123-4)	Fast mode:	3 mm + 1.5 ppm / typ. 0.8 s
	Tracking mode:	3 mm + 1.5 ppm / typ. <0.15 s
	Display resolution:	0.1 mm
Method	Special phase shift analyzer (coaxial, visible red laser)	

PinPoint R400/R1000 reflectorless distance measurement (RL-Mode)

Range	PinPoint R400:	400 m / 200 m (Kodak Gray Card: 90 % reflective / 18 % reflective)
(average atmospheric conditions)	PinPoint R1000:	1000 m / 500 m (Kodak Gray Card: 90 % reflective / 18 % reflective)
	Shortest measurable distance:	1.5 m
	Long Range to round prism (GPR1):	1000 m – 7500 m
Accuracy / Measurement time	Reflectorless < 500 m:	2 mm + 2 ppm / typ. 3 – 6 s, max. 12 s
(standard deviation, ISO 17123-4)	Reflectorless > 500 m:	4 mm + 2 ppm / typ. 3 – 6 s, max. 12 s
(object in shade, sky overcast)	Long Range:	5 mm + 2 ppm / typ. 2.5 s, max. 12 s
Laser dot size	At 20 m:	approx. 7 mm x 14 mm
	At 100 m:	approx. 12 mm x 40 mm
Method	PinPoint R400 / R1000:	System analyzer (coaxial, visible red laser)

Motorized

Maximum speed	Rotating speed:	45° / s

Automatic Target Recognition (ATR)

Range ATR mode / LOCK mode	Round prism (GPR1):	1000 m / 800 m
(average atmospheric conditions)	360° reflector (GRZ4, GRZ122):	600 m / 500 m
	Mini prism (GMP101):	500 m / 400 m
	Reflective tape (60 mm x 60 mm):	55 m (175 ft)
	Shortest measurable distance:	1.5 m / 5 m
Accuracy / Measure time	ATR angle accuracy Hz, V:	1 " (0.3 mgon)
(std. dev. ISO 17123-3)	Base positioning accuracy:	± 1mm
	Measure time for GPR1:	3 – 4 s
Maximum speed (LOCK mode)	Tangential (standard mode):	5 m / s at 20 m, 25 m / s at 100 m
	Radial (tracking mode):	4 m / s
Method	Digital image processing (laser beam)	

PowerSearch (PS)

Range	Round prism (GPR1):	300 m
(average atmospheric conditions)	360° reflector (GRZ4, GRZ122):	300 m (perfectly aligned to instrument)
	Mini prism (GMP101):	100 m
	Shortest distance:	5 m
Search time	Typical search time:	< 10 s
Maximum speed	Rotating speed:	45° / s
Method	Digital signal processing (rotating laser fan)	

Guide Light (EGL)

Range		
(average atmospheric conditions)	Working range:	5 m – 150 m
Accuracy	Positioning accuracy:	5 cm at 100 m

General data

Telescope	
Magnification:	30 x
Free objective aperture:	40 mm
Field of view:	1°30' (1.66 gon) / 2.7 m at 100 m
Focusing range:	1.7 m to infinity
Keyboard and Display	
Display:	1/4 VGA (320*240 pixels), graphic LCD, colour, illumination, touch screen
Keyboard:	34 keys (12 function keys, 12 alphanumeric keys), illumination
Angle display:	360° ' ", 360° decimal, 400 gon, 6400 mil, V%
Distance display:	meter, int. ft, int. ft/inch, US ft, US ft/inch
Position:	face I standard / face II optional
Data storage	
Internal memory:	64 MB (optional)
Memory card:	CompactFlash cards (64 MB and 256 MB)
Number of data records:	1750 / MB
Interfaces:	RS232, *Bluetooth®* Wireless-Technology (optional)
Circular Level	
Sensitivity:	6' / 2 mm

Laser plummet	
Centering accuracy:	1.5 mm at 1.5 m
Laser dot diameter:	2.5 mm at 1.5 m
Endless drives	
Number of drives:	1 horizontal / 1 vertical
Battery (GEB221)	
Type:	Lithium-Ion
Voltage:	7.4 V
Capacity:	3.8 Ah
Operating time:	typ. 5 – 8 h
Weights	
Total station:	4.8 – 5.5 kg
Battery (GEB221):	0.2 kg
Tribrach (GDF121):	0.8 kg
Environmental specifications	
Working temperature range:	–20° C to +50° C
Storage temperature range:	–40° C to +70° C
Dust / water (IEC 60529):	IP54
Humidity:	95 %, non-condensing

Remote Control Unit (RX1250T/Tc)

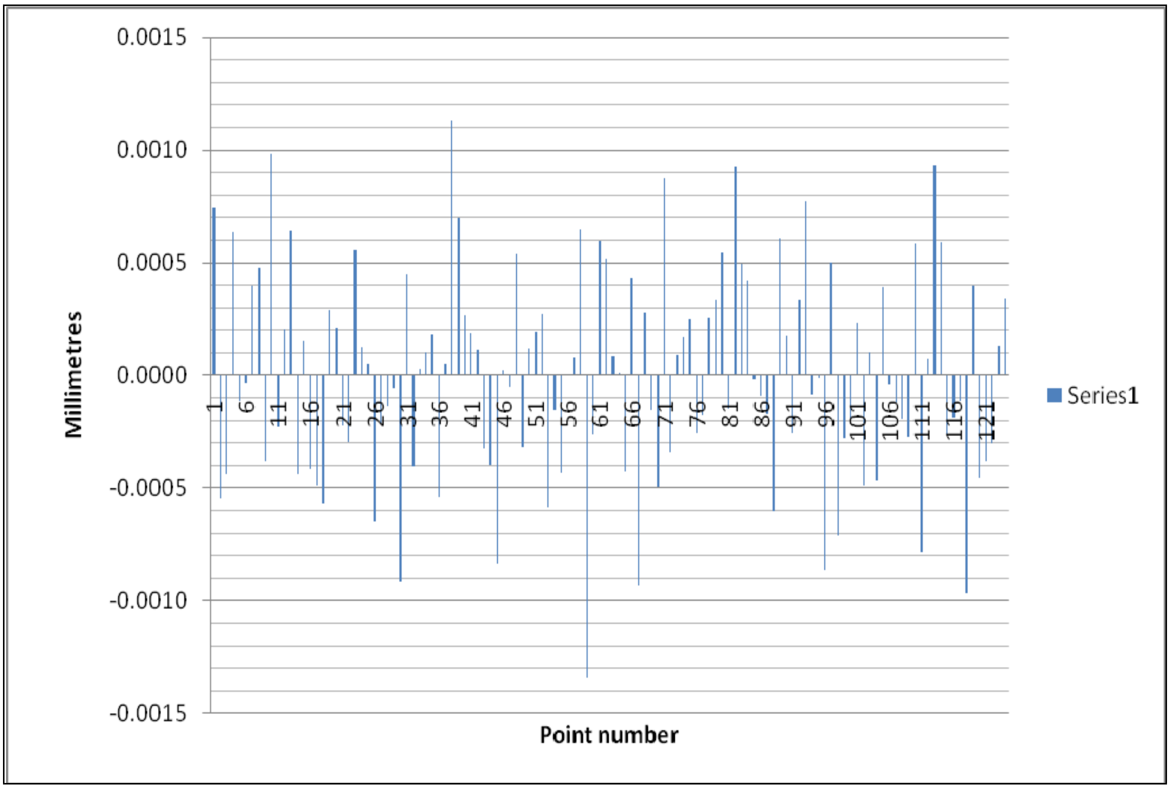
Communication	via integrated radio modem	
Control unit	Display:	1/4 VGA (320*240 pixels), graphic LCD, touch screen, illumination
	Keyboard:	62 keys (12 function keys, 40 alphanumeric keys), illumination
	Interface:	RS232
Battery (GEB211)	Type:	Lithium-Ion
	Voltage:	7.4 V
	Capacity:	1.9 Ah
	Operating time:	RX1250T: typ. 9h, RX1250Tc: typ. 8h
Weights	Control unit RX1250T/Tc:	0.8 kg
	Battery (GEB211):	0.1 kg
	Reflector pole adapter:	0.25 kg
Environmental specifications	Working temperature range:	RX1250T –30° C to +65° C / RX1250Tc –30° C to +50° C
	Storage temperature range:	–40° C to +80° C
	Protection against water, dust and sand	IP67
	(IEC 60529, MIL-STD-810F)	waterproof to 1 m temporary submersion, dust tight

Appendix D – S6 Dry Conditions.

Point	Easting	Northing	RL	Normal	ABS	Average	Standard Dev
2000	995.267	5006.196	100.426	0.0007	0.0007	0.00037	0.00027
2001	995.266	5006.197	100.426	-0.0005	0.0005		
2002	995.443	5006.661	100.44	-0.0004	0.0004		
2003	995.269	5006.202	99.926	0.0006	0.0006		
2004	995.284	5006.243	100.427	-0.0001	0.0001		
2005	995.302	5006.29	100.429	0.0000	0.0000		
2006	995.32	5006.336	100.43	0.0004	0.0004		
2007	995.338	5006.383	100.432	0.0005	0.0005		
2008	995.355	5006.43	100.433	-0.0004	0.0004		
2009	995.374	5006.476	100.435	0.0010	0.0010		
2010	995.391	5006.524	100.436	-0.0002	0.0002		
2011	995.409	5006.57	100.438	0.0002	0.0002		
2012	995.427	5006.616	100.439	0.0006	0.0006		
2013	995.443	5006.661	100.44	-0.0004	0.0004		
2014	995.444	5006.662	100.39	0.0002	0.0002		
2015	995.427	5006.619	100.389	-0.0004	0.0004		
2016	995.409	5006.572	100.388	-0.0005	0.0005		
2017	995.391	5006.525	100.386	-0.0006	0.0006		
2018	995.374	5006.478	100.385	0.0003	0.0003		
2019	995.356	5006.431	100.383	0.0002	0.0002		
2020	995.338	5006.385	100.382	-0.0002	0.0002		
2021	995.32	5006.338	100.38	-0.0003	0.0003		
2022	995.303	5006.291	100.379	0.0006	0.0006		
2023	995.285	5006.245	100.377	0.0001	0.0001		
2024	995.267	5006.198	100.376	0.0000	0.0000		
2025	995.267	5006.2	100.326	-0.0006	0.0006		
2026	995.285	5006.246	100.327	-0.0002	0.0002		
2027	995.303	5006.293	100.329	-0.0001	0.0001		
2028	995.321	5006.34	100.33	-0.0001	0.0001		
2029	995.338	5006.387	100.332	-0.0009	0.0009		
2030	995.357	5006.433	100.333	0.0005	0.0005		
2031	995.374	5006.48	100.335	-0.0004	0.0004		
2032	995.392	5006.526	100.336	0.0000	0.0000		
2033	995.41	5006.573	100.338	0.0001	0.0001		
2034	995.428	5006.62	100.339	0.0002	0.0002		
2035	995.444	5006.664	100.34	-0.0005	0.0005		
2036	995.445	5006.665	100.29	0.0001	0.0001		
2037	995.429	5006.62	100.289	0.0011	0.0011		
2038	995.411	5006.574	100.288	0.0007	0.0007		
2039	995.393	5006.528	100.286	0.0003	0.0003		
2040	995.375	5006.481	100.285	0.0002	0.0002		
2041	995.357	5006.434	100.283	0.0001	0.0001		
2042	995.339	5006.388	100.282	-0.0003	0.0003		
2043	995.321	5006.341	100.28	-0.0004	0.0004		
2044	995.303	5006.295	100.279	-0.0008	0.0008		
2045	995.286	5006.248	100.277	0.0000	0.0000		
2046	995.268	5006.201	100.276	-0.0001	0.0001		
2047	995.269	5006.202	100.226	0.0005	0.0005		

2048	995.286	5006.249	100.227	-0.0003	0.0003
2049	995.304	5006.295	100.229	0.0001	0.0001
2050	995.322	5006.342	100.23	0.0002	0.0002
2051	995.34	5006.389	100.232	0.0003	0.0003
2052	995.357	5006.436	100.233	-0.0006	0.0006
2053	995.375	5006.482	100.235	-0.0002	0.0002
2054	995.393	5006.53	100.236	-0.0004	0.0004
2055	995.411	5006.576	100.238	0.0000	0.0000
2056	995.429	5006.623	100.239	0.0001	0.0001
2057	995.446	5006.666	100.24	0.0006	0.0006
2058	995.445	5006.669	100.191	-0.0013	0.0013
2059	995.429	5006.624	100.189	-0.0003	0.0003
2060	995.412	5006.577	100.188	0.0006	0.0006
2061	995.394	5006.53	100.186	0.0005	0.0005
2062	995.376	5006.484	100.185	0.0001	0.0001
2063	995.358	5006.437	100.183	0.0000	0.0000
2064	995.34	5006.391	100.182	-0.0004	0.0004
2065	995.323	5006.344	100.18	0.0004	0.0004
2066	995.304	5006.298	100.179	-0.0009	0.0009
2067	995.287	5006.25	100.177	0.0003	0.0003
2068	995.269	5006.204	100.176	-0.0002	0.0002
2069	995.269	5006.205	100.126	-0.0005	0.0005
2070	995.288	5006.251	100.127	0.0009	0.0009
2071	995.305	5006.299	100.129	-0.0003	0.0003
2072	995.323	5006.345	100.13	0.0001	0.0001
2073	995.341	5006.392	100.132	0.0002	0.0002
2074	995.359	5006.439	100.133	0.0002	0.0002
2075	995.376	5006.485	100.135	-0.0003	0.0003
2076	995.394	5006.532	100.136	-0.0002	0.0002
2077	995.412	5006.578	100.138	0.0003	0.0003
2078	995.43	5006.625	100.139	0.0003	0.0003
2079	995.447	5006.669	100.141	0.0005	0.0005
2080	995.447	5006.671	100.091	-0.0002	0.0002
2081	995.431	5006.626	100.089	0.0009	0.0009
2082	995.413	5006.58	100.088	0.0005	0.0005
2083	995.395	5006.533	100.086	0.0004	0.0004
2084	995.377	5006.487	100.085	0.0000	0.0000
2085	995.359	5006.44	100.083	-0.0001	0.0001
2086	995.341	5006.393	100.082	-0.0002	0.0002
2087	995.323	5006.347	100.08	-0.0006	0.0006
2088	995.306	5006.299	100.079	0.0006	0.0006
2089	995.288	5006.253	100.077	0.0002	0.0002
2090	995.27	5006.207	100.076	-0.0003	0.0003
2091	995.271	5006.208	100.026	0.0003	0.0003
2092	995.289	5006.254	100.027	0.0008	0.0008
2093	995.306	5006.301	100.029	-0.0001	0.0001
2094	995.324	5006.348	100.03	0.0000	0.0000
2095	995.341	5006.395	100.032	-0.0009	0.0009
2096	995.36	5006.441	100.033	0.0005	0.0005
2097	995.377	5006.489	100.035	-0.0007	0.0007
2098	995.395	5006.535	100.036	-0.0003	0.0003
2099	995.413	5006.582	100.038	-0.0002	0.0002

2100	995.431	5006.628	100.039	0.0002	0.0002
2101	995.447	5006.672	100.041	-0.0005	0.0005
2102	995.448	5006.673	99.991	0.0001	0.0001
2103	995.431	5006.63	99.989	-0.0005	0.0005
2104	995.414	5006.583	99.988	0.0004	0.0004
2105	995.396	5006.537	99.986	0.0000	0.0000
2106	995.378	5006.49	99.985	-0.0001	0.0001
2107	995.36	5006.443	99.983	-0.0002	0.0002
2108	995.342	5006.396	99.982	-0.0003	0.0003
2109	995.325	5006.349	99.98	0.0006	0.0006
2110	995.306	5006.303	99.979	-0.0008	0.0008
2111	995.289	5006.256	99.977	0.0001	0.0001
2112	995.272	5006.209	99.976	0.0009	0.0009
2113	995.272	5006.21	99.927	0.0006	0.0006
2114	995.289	5006.257	99.928	-0.0003	0.0003
2115	995.307	5006.304	99.93	-0.0002	0.0002
2116	995.325	5006.351	99.931	-0.0001	0.0001
2117	995.342	5006.398	99.933	-0.0010	0.0010
2118	995.361	5006.444	99.934	0.0004	0.0004
2119	995.378	5006.491	99.936	-0.0005	0.0005
2120	995.396	5006.538	99.937	-0.0004	0.0004
2121	995.414	5006.585	99.939	-0.0003	0.0003
2122	995.432	5006.631	99.94	0.0001	0.0001
2123	995.449	5006.675	99.941	0.0003	0.0003

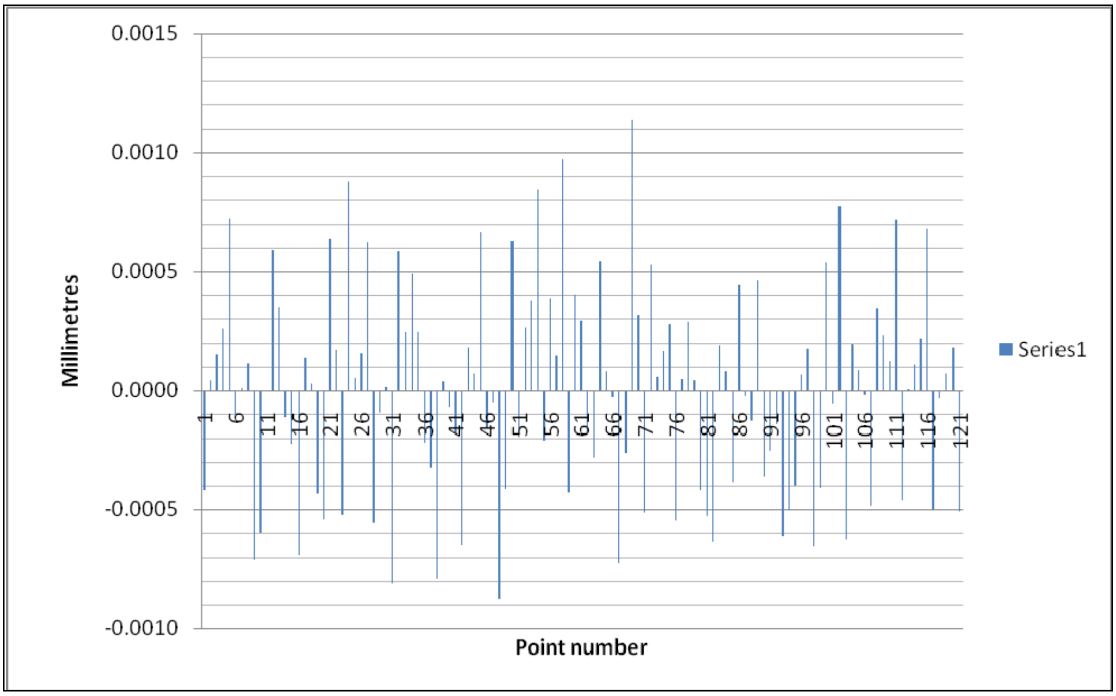


Appendix E – S6 Wet Conditions.

Point	Easting	Northing	RL	Normal	ABS	Average	Standard Dev
5000	995.266	5006.197	100.426	-0.0004	0.0004	0.00035	0.00026
5001	995.284	5006.243	100.427	0.0000	0.0000		
5002	995.302	5006.29	100.429	0.0002	0.0002		
5003	995.32	5006.337	100.43	0.0003	0.0003		
5004	995.338	5006.383	100.432	0.0007	0.0007		
5005	995.355	5006.43	100.433	-0.0001	0.0001		
5006	995.373	5006.477	100.435	0.0000	0.0000		
5007	995.391	5006.524	100.436	0.0001	0.0001		
5008	995.408	5006.571	100.438	-0.0007	0.0007		
5009	995.426	5006.618	100.439	-0.0006	0.0006		
5010	995.443	5006.661	100.44	0.0000	0.0000		
5011	995.444	5006.662	100.39	0.0006	0.0006		
5012	995.427	5006.618	100.389	0.0003	0.0003		
5013	995.409	5006.572	100.388	-0.0001	0.0001		
5014	995.391	5006.525	100.386	-0.0002	0.0002		
5015	995.373	5006.479	100.385	-0.0007	0.0007		
5016	995.356	5006.432	100.383	0.0001	0.0001		
5017	995.338	5006.385	100.382	0.0000	0.0000		
5018	995.32	5006.339	100.38	-0.0004	0.0004		
5019	995.302	5006.292	100.379	-0.0005	0.0005		
5020	995.285	5006.244	100.377	0.0006	0.0006		
5021	995.267	5006.198	100.376	0.0002	0.0002		
5022	995.267	5006.2	100.326	-0.0005	0.0005		
5023	995.286	5006.246	100.327	0.0009	0.0009		
5024	995.303	5006.293	100.329	0.0001	0.0001		
5025	995.321	5006.34	100.33	0.0002	0.0002		
5026	995.339	5006.386	100.332	0.0006	0.0006		
5027	995.356	5006.434	100.333	-0.0006	0.0006		
5028	995.374	5006.48	100.335	-0.0001	0.0001		
5029	995.392	5006.527	100.336	0.0000	0.0000		
5030	995.409	5006.574	100.338	-0.0008	0.0008		
5031	995.428	5006.62	100.339	0.0006	0.0006		
5032	995.444	5006.663	100.34	0.0003	0.0003		
5033	995.445	5006.665	100.291	0.0005	0.0005		
5034	995.428	5006.621	100.289	0.0002	0.0002		
5035	995.41	5006.575	100.288	-0.0002	0.0002		
5036	995.392	5006.528	100.286	-0.0003	0.0003		
5037	995.374	5006.482	100.285	-0.0008	0.0008		
5038	995.357	5006.435	100.283	0.0000	0.0000		
5039	995.339	5006.388	100.282	-0.0001	0.0001		
5040	995.321	5006.341	100.28	-0.0002	0.0002		
5041	995.303	5006.295	100.279	-0.0006	0.0006		
5042	995.286	5006.248	100.277	0.0002	0.0002		
5043	995.268	5006.201	100.276	0.0001	0.0001		
5044	995.269	5006.202	100.226	0.0007	0.0007		
5045	995.286	5006.249	100.227	-0.0002	0.0002		
5046	995.304	5006.296	100.229	0.0000	0.0000		
5047	995.321	5006.343	100.23	-0.0009	0.0009		

5048	995.339	5006.389	100.232	-0.0004	0.0004
5049	995.358	5006.436	100.233	0.0006	0.0006
5050	995.375	5006.483	100.235	-0.0002	0.0002
5051	995.393	5006.529	100.236	0.0003	0.0003
5052	995.411	5006.576	100.238	0.0004	0.0004
5053	995.429	5006.622	100.239	0.0008	0.0008
5054	995.445	5006.667	100.241	-0.0002	0.0002
5055	995.446	5006.668	100.191	0.0004	0.0004
5056	995.429	5006.624	100.189	0.0001	0.0001
5057	995.412	5006.577	100.188	0.0010	0.0010
5058	995.393	5006.531	100.186	-0.0004	0.0004
5059	995.376	5006.484	100.185	0.0004	0.0004
5060	995.358	5006.437	100.183	0.0003	0.0003
5061	995.34	5006.391	100.182	-0.0002	0.0002
5062	995.322	5006.344	100.18	-0.0003	0.0003
5063	995.305	5006.297	100.179	0.0005	0.0005
5064	995.287	5006.251	100.177	0.0001	0.0001
5065	995.269	5006.204	100.176	0.0000	0.0000
5066	995.269	5006.206	100.126	-0.0007	0.0007
5067	995.287	5006.252	100.127	-0.0003	0.0003
5068	995.306	5006.298	100.129	0.0011	0.0011
5069	995.323	5006.345	100.13	0.0003	0.0003
5070	995.34	5006.392	100.132	-0.0005	0.0005
5071	995.359	5006.439	100.133	0.0005	0.0005
5072	995.376	5006.485	100.135	0.0001	0.0001
5073	995.394	5006.532	100.136	0.0002	0.0002
5074	995.412	5006.579	100.138	0.0003	0.0003
5075	995.429	5006.626	100.139	-0.0005	0.0005
5076	995.446	5006.669	100.141	0.0000	0.0000
5077	995.447	5006.671	100.091	0.0003	0.0003
5078	995.43	5006.627	100.089	0.0000	0.0000
5079	995.412	5006.581	100.088	-0.0004	0.0004
5080	995.394	5006.534	100.086	-0.0005	0.0005
5081	995.376	5006.487	100.085	-0.0006	0.0006
5082	995.359	5006.44	100.083	0.0002	0.0002
5083	995.341	5006.393	100.082	0.0001	0.0001
5084	995.323	5006.347	100.08	-0.0004	0.0004
5085	995.306	5006.3	100.079	0.0004	0.0004
5086	995.288	5006.254	100.077	0.0000	0.0000
5087	995.27	5006.207	100.076	-0.0001	0.0001
5088	995.271	5006.208	100.026	0.0005	0.0005
5089	995.288	5006.255	100.027	-0.0004	0.0004
5090	995.306	5006.302	100.029	-0.0003	0.0003
5091	995.324	5006.349	100.03	-0.0001	0.0001
5092	995.341	5006.395	100.032	-0.0006	0.0006
5093	995.359	5006.442	100.033	-0.0005	0.0005
5094	995.377	5006.489	100.035	-0.0004	0.0004
5095	995.395	5006.535	100.036	0.0001	0.0001
5096	995.413	5006.582	100.038	0.0002	0.0002
5097	995.43	5006.629	100.039	-0.0006	0.0006
5098	995.447	5006.673	100.041	-0.0004	0.0004
5099	995.448	5006.673	99.991	0.0005	0.0005

5100	995.431	5006.63	99.989	-0.0001	0.0001
5101	995.414	5006.583	99.988	0.0008	0.0008
5102	995.395	5006.537	99.986	-0.0006	0.0006
5103	995.378	5006.49	99.985	0.0002	0.0002
5104	995.36	5006.443	99.983	0.0001	0.0001
5105	995.342	5006.396	99.982	0.0000	0.0000
5106	995.324	5006.35	99.98	-0.0005	0.0005
5107	995.307	5006.303	99.979	0.0003	0.0003
5108	995.289	5006.256	99.977	0.0002	0.0002
5109	995.271	5006.209	99.976	0.0001	0.0001
5110	995.272	5006.21	99.927	0.0007	0.0007
5111	995.289	5006.258	99.928	-0.0005	0.0005
5112	995.307	5006.304	99.93	0.0000	0.0000
5113	995.325	5006.351	99.931	0.0001	0.0001
5114	995.343	5006.398	99.933	0.0002	0.0002
5115	995.361	5006.444	99.934	0.0007	0.0007
5116	995.378	5006.492	99.936	-0.0005	0.0005
5117	995.396	5006.538	99.937	0.0000	0.0000
5118	995.414	5006.585	99.939	0.0001	0.0001
5119	995.432	5006.632	99.94	0.0002	0.0002
5120	995.448	5006.676	99.941	-0.0005	0.0005

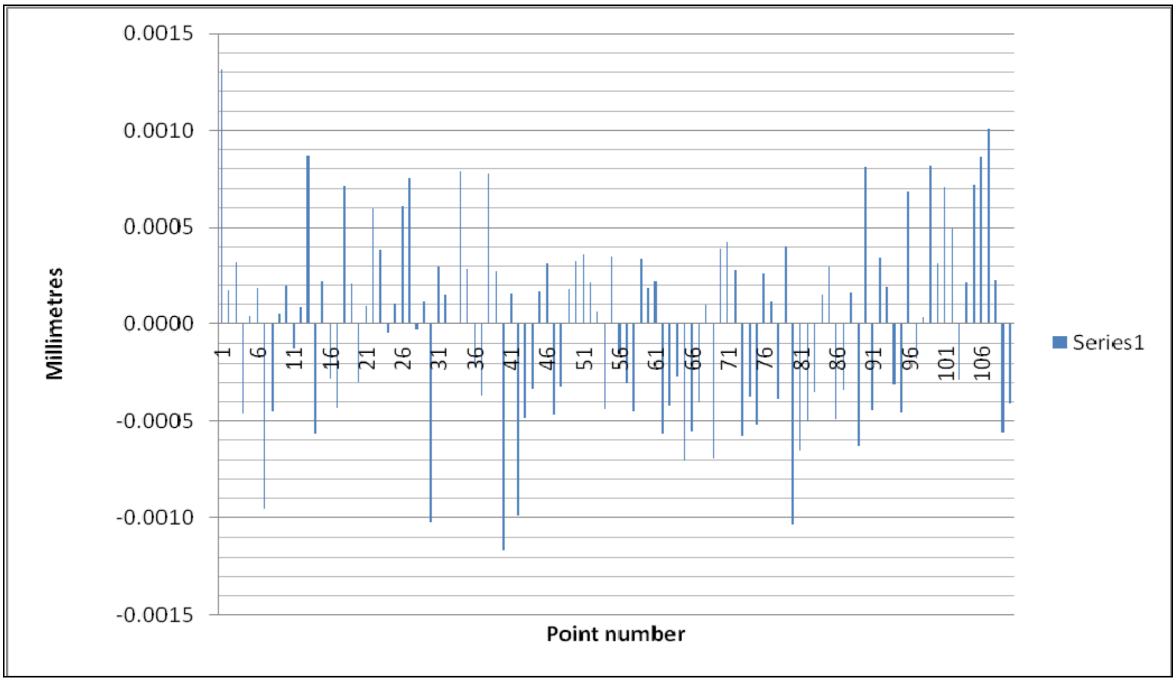


Appendix F – Leica Dry Conditions.

Point	Easting	Northing	RL	Normal	ABS	Average	Standard Dev
2000	995.265	5006.198	101.94	0.0013	0.0013	0.00041	0.00027
2001	995.282	5006.246	101.94	0.0002	0.0002		
2002	995.3	5006.293	101.94	0.0003	0.0003		
2003	995.317	5006.34	101.94	-0.0005	0.0005		
2004	995.335	5006.386	101.94	0.0000	0.0000		
2005	995.353	5006.433	101.94	0.0002	0.0002		
2006	995.37	5006.481	101.94	-0.0010	0.0010		
2007	995.388	5006.527	101.94	-0.0005	0.0005		
2008	995.406	5006.573	101.94	0.0001	0.0001		
2009	995.424	5006.62	101.94	0.0002	0.0002		
2010	995.424	5006.621	101.89	-0.0001	0.0001		
2011	995.406	5006.573	101.89	0.0001	0.0001		
2012	995.389	5006.526	101.89	0.0009	0.0009		
2013	995.37	5006.48	101.89	-0.0006	0.0006		
2014	995.353	5006.433	101.89	0.0002	0.0002		
2015	995.335	5006.387	101.89	-0.0003	0.0003		
2016	995.317	5006.34	101.89	-0.0004	0.0004		
2017	995.3	5006.292	101.89	0.0007	0.0007		
2018	995.282	5006.246	101.89	0.0002	0.0002		
2019	995.264	5006.2	101.89	-0.0003	0.0003		
2020	995.264	5006.199	101.84	0.0001	0.0001		
2021	995.282	5006.245	101.84	0.0006	0.0006		
2022	995.3	5006.293	101.84	0.0004	0.0004		
2023	995.317	5006.339	101.84	0.0000	0.0000		
2024	995.335	5006.386	101.84	0.0001	0.0001		
2025	995.353	5006.432	101.84	0.0006	0.0006		
2026	995.371	5006.479	101.84	0.0008	0.0008		
2027	995.388	5006.526	101.84	0.0000	0.0000		
2028	995.406	5006.573	101.84	0.0001	0.0001		
2029	995.423	5006.621	101.84	-0.0010	0.0010		
2030	995.424	5006.62	101.79	0.0003	0.0003		
2031	995.406	5006.573	101.79	0.0001	0.0001		
2032	995.388	5006.526	101.79	0.0000	0.0000		
2033	995.371	5006.479	101.79	0.0008	0.0008		
2034	995.353	5006.433	101.79	0.0003	0.0003		
2035	995.335	5006.387	101.79	-0.0002	0.0002		
2036	995.317	5006.34	101.79	-0.0004	0.0004		
2037	995.3	5006.292	101.79	0.0008	0.0008		
2038	995.282	5006.246	101.79	0.0003	0.0003		
2039	995.263	5006.2	101.79	-0.0012	0.0012		
2040	995.264	5006.199	101.74	0.0002	0.0002		
2041	995.281	5006.247	101.74	-0.0010	0.0010		
2042	995.299	5006.293	101.74	-0.0005	0.0005		
2043	995.317	5006.34	101.74	-0.0003	0.0003		
2044	995.335	5006.386	101.74	0.0002	0.0002		
2045	995.353	5006.433	101.74	0.0003	0.0003		
2046	995.37	5006.48	101.74	-0.0005	0.0005		
2047	995.388	5006.527	101.74	-0.0003	0.0003		

2048	995.406	5006.573	101.74	0.0002	0.0002
2049	995.424	5006.62	101.74	0.0003	0.0003
2050	995.424	5006.62	101.69	0.0004	0.0004
2051	995.406	5006.573	101.69	0.0002	0.0002
2052	995.388	5006.526	101.69	0.0001	0.0001
2053	995.37	5006.48	101.69	-0.0004	0.0004
2054	995.353	5006.433	101.69	0.0003	0.0003
2055	995.335	5006.387	101.69	-0.0002	0.0002
2056	995.317	5006.34	101.69	-0.0003	0.0003
2057	995.299	5006.293	101.69	-0.0005	0.0005
2058	995.282	5006.246	101.69	0.0003	0.0003
2059	995.264	5006.199	101.69	0.0002	0.0002
2060	995.264	5006.199	101.64	0.0002	0.0002
2061	995.281	5006.246	101.64	-0.0006	0.0006
2062	995.299	5006.293	101.64	-0.0004	0.0004
2063	995.317	5006.34	101.64	-0.0003	0.0003
2064	995.334	5006.386	101.64	-0.0007	0.0007
2065	995.352	5006.433	101.64	-0.0006	0.0006
2066	995.37	5006.48	101.64	-0.0004	0.0004
2067	995.388	5006.526	101.64	0.0001	0.0001
2068	995.405	5006.573	101.64	-0.0007	0.0007
2069	995.424	5006.62	101.64	0.0004	0.0004
2070	995.424	5006.62	101.59	0.0004	0.0004
2071	995.406	5006.573	101.59	0.0003	0.0003
2072	995.388	5006.528	101.59	-0.0006	0.0006
2073	995.37	5006.48	101.59	-0.0004	0.0004
2074	995.352	5006.433	101.59	-0.0005	0.0005
2075	995.335	5006.386	101.59	0.0003	0.0003
2076	995.317	5006.339	101.59	0.0001	0.0001
2077	995.299	5006.293	101.59	-0.0004	0.0004
2078	995.282	5006.246	101.59	0.0004	0.0004
2079	995.263	5006.2	101.59	-0.0010	0.0010
2080	995.263	5006.199	101.54	-0.0007	0.0007
2081	995.281	5006.246	101.54	-0.0005	0.0005
2082	995.299	5006.293	101.54	-0.0004	0.0004
2083	995.317	5006.339	101.54	0.0001	0.0001
2084	995.335	5006.386	101.54	0.0003	0.0003
2085	995.352	5006.433	101.54	-0.0005	0.0005
2086	995.37	5006.48	101.54	-0.0003	0.0003
2087	995.388	5006.526	101.54	0.0002	0.0002
2088	995.405	5006.573	101.54	-0.0006	0.0006
2089	995.424	5006.619	101.54	0.0008	0.0008
2090	995.423	5006.62	101.49	-0.0004	0.0004
2091	995.406	5006.573	101.49	0.0003	0.0003
2092	995.388	5006.526	101.49	0.0002	0.0002
2093	995.37	5006.48	101.49	-0.0003	0.0003
2094	995.352	5006.433	101.49	-0.0005	0.0005
2095	995.335	5006.385	101.49	0.0007	0.0007
2096	995.317	5006.34	101.49	-0.0002	0.0002
2097	995.299	5006.292	101.49	0.0000	0.0000
2098	995.282	5006.245	101.49	0.0008	0.0008
2099	995.264	5006.199	101.49	0.0003	0.0003

2100	995.264	5006.198	101.44	0.0007	0.0007
2101	995.282	5006.246	101.44	0.0005	0.0005
2102	995.299	5006.293	101.44	-0.0003	0.0003
2103	995.317	5006.339	101.44	0.0002	0.0002
2104	995.335	5006.385	101.44	0.0007	0.0007
2105	995.353	5006.432	101.44	0.0009	0.0009
2106	995.371	5006.479	101.44	0.0010	0.0010
2107	995.388	5006.526	101.44	0.0002	0.0002
2108	995.405	5006.573	101.44	-0.0006	0.0006
2109	995.423	5006.62	101.44	-0.0004	0.0004

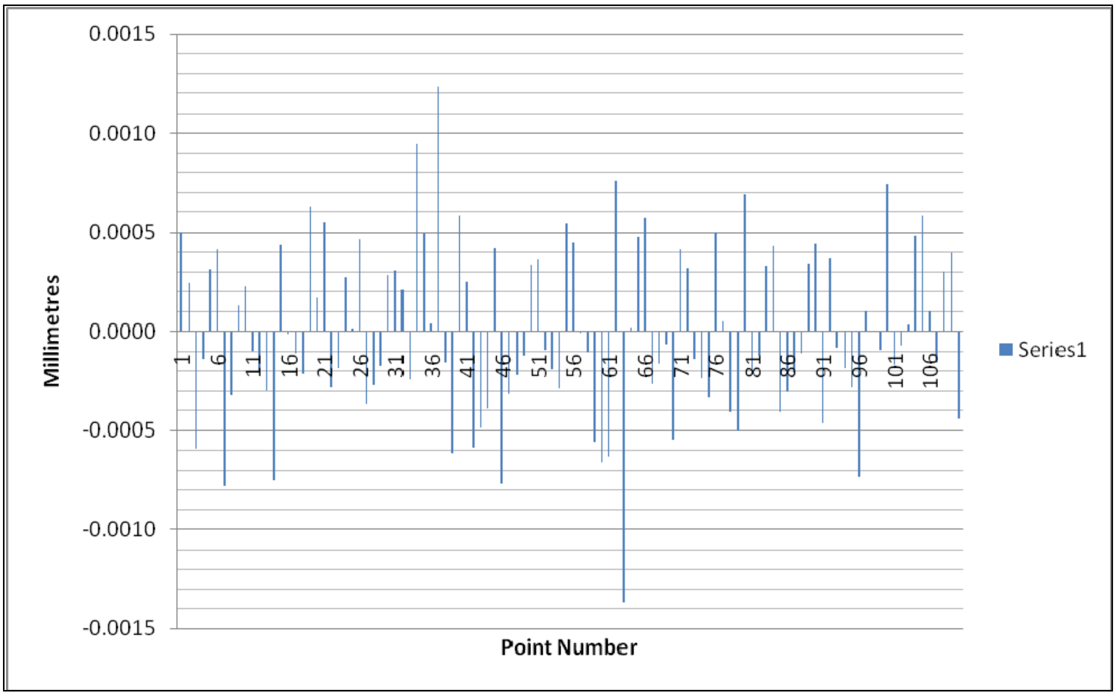


Appendix G – Leica Wet Conditions.

Point	Easting	Northing	RL	Normal	ABS	Average	Standard Dev
4000	995.264	5006.199	101.94	0.0005	0.0005	0.00035	0.00025
4001	995.282	5006.247	101.94	0.0002	0.0002		
4002	995.299	5006.294	101.94	-0.0006	0.0006		
4003	995.317	5006.34	101.94	-0.0001	0.0001		
4004	995.335	5006.386	101.94	0.0003	0.0003		
4005	995.353	5006.433	101.94	0.0004	0.0004		
4006	995.37	5006.481	101.94	-0.0008	0.0008		
4007	995.388	5006.527	101.94	-0.0003	0.0003		
4008	995.406	5006.573	101.94	0.0001	0.0001		
4009	995.424	5006.62	101.94	0.0002	0.0002		
4010	995.424	5006.621	101.89	-0.0001	0.0001		
4011	995.406	5006.574	101.89	-0.0002	0.0002		
4012	995.388	5006.527	101.89	-0.0003	0.0003		
4013	995.37	5006.481	101.89	-0.0008	0.0008		
4014	995.353	5006.433	101.89	0.0004	0.0004		
4015	995.335	5006.387	101.89	0.0000	0.0000		
4016	995.317	5006.34	101.89	-0.0001	0.0001		
4017	995.299	5006.293	101.89	-0.0002	0.0002		
4018	995.282	5006.246	101.89	0.0006	0.0006		
4019	995.264	5006.2	101.89	0.0002	0.0002		
4020	995.264	5006.199	101.84	0.0006	0.0006		
4021	995.281	5006.246	101.84	-0.0003	0.0003		
4022	995.299	5006.293	101.84	-0.0002	0.0002		
4023	995.317	5006.339	101.84	0.0003	0.0003		
4024	995.335	5006.387	101.84	0.0000	0.0000		
4025	995.353	5006.433	101.84	0.0005	0.0005		
4026	995.37	5006.48	101.84	-0.0004	0.0004		
4027	995.388	5006.527	101.84	-0.0003	0.0003		
4028	995.406	5006.574	101.84	-0.0002	0.0002		
4029	995.424	5006.62	101.84	0.0003	0.0003		
4030	995.424	5006.62	101.79	0.0003	0.0003		
4031	995.406	5006.573	101.79	0.0002	0.0002		
4032	995.388	5006.527	101.79	-0.0002	0.0002		
4033	995.371	5006.479	101.79	0.0009	0.0009		
4034	995.353	5006.433	101.79	0.0005	0.0005		
4035	995.335	5006.387	101.79	0.0000	0.0000		
4036	995.318	5006.339	101.79	0.0012	0.0012		
4037	995.299	5006.293	101.79	-0.0002	0.0002		
4038	995.281	5006.247	101.79	-0.0006	0.0006		
4039	995.264	5006.199	101.79	0.0006	0.0006		
4040	995.264	5006.2	101.74	0.0003	0.0003		
4041	995.281	5006.247	101.74	-0.0006	0.0006		
4042	995.299	5006.294	101.74	-0.0005	0.0005		
4043	995.317	5006.341	101.74	-0.0004	0.0004		
4044	995.335	5006.386	101.74	0.0004	0.0004		
4045	995.352	5006.434	101.74	-0.0008	0.0008		
4046	995.37	5006.48	101.74	-0.0003	0.0003		
4047	995.388	5006.527	101.74	-0.0002	0.0002		

4048	995.406	5006.574	101.74	-0.0001	0.0001
4049	995.424	5006.62	101.74	0.0003	0.0003
4050	995.424	5006.62	101.69	0.0004	0.0004
4051	995.406	5006.574	101.69	-0.0001	0.0001
4052	995.388	5006.527	101.69	-0.0002	0.0002
4053	995.37	5006.48	101.69	-0.0003	0.0003
4054	995.353	5006.433	101.69	0.0005	0.0005
4055	995.335	5006.386	101.69	0.0004	0.0004
4056	995.317	5006.34	101.69	0.0000	0.0000
4057	995.299	5006.293	101.69	-0.0001	0.0001
4058	995.281	5006.247	101.69	-0.0006	0.0006
4059	995.263	5006.2	101.69	-0.0007	0.0007
4060	995.263	5006.2	101.64	-0.0006	0.0006
4061	995.282	5006.246	101.64	0.0008	0.0008
4062	995.298	5006.294	101.64	-0.0014	0.0014
4063	995.317	5006.34	101.64	0.0000	0.0000
4064	995.335	5006.386	101.64	0.0005	0.0005
4065	995.353	5006.433	101.64	0.0006	0.0006
4066	995.37	5006.48	101.64	-0.0003	0.0003
4067	995.388	5006.527	101.64	-0.0002	0.0002
4068	995.406	5006.574	101.64	-0.0001	0.0001
4069	995.423	5006.62	101.64	-0.0005	0.0005
4070	995.424	5006.62	101.59	0.0004	0.0004
4071	995.406	5006.573	101.59	0.0003	0.0003
4072	995.388	5006.527	101.59	-0.0001	0.0001
4073	995.37	5006.48	101.59	-0.0002	0.0002
4074	995.352	5006.433	101.59	-0.0003	0.0003
4075	995.335	5006.386	101.59	0.0005	0.0005
4076	995.317	5006.34	101.59	0.0000	0.0000
4077	995.299	5006.294	101.59	-0.0004	0.0004
4078	995.281	5006.247	101.59	-0.0005	0.0005
4079	995.264	5006.199	101.59	0.0007	0.0007
4080	995.263	5006.199	101.54	-0.0002	0.0002
4081	995.281	5006.246	101.54	-0.0001	0.0001
4082	995.299	5006.292	101.54	0.0003	0.0003
4083	995.317	5006.339	101.54	0.0004	0.0004
4084	995.334	5006.386	101.54	-0.0004	0.0004
4085	995.352	5006.433	101.54	-0.0003	0.0003
4086	995.37	5006.48	101.54	-0.0002	0.0002
4087	995.388	5006.527	101.54	-0.0001	0.0001
4088	995.406	5006.573	101.54	0.0003	0.0003
4089	995.424	5006.62	101.54	0.0004	0.0004
4090	995.423	5006.62	101.49	-0.0005	0.0005
4091	995.406	5006.573	101.49	0.0004	0.0004
4092	995.388	5006.527	101.49	-0.0001	0.0001
4093	995.37	5006.48	101.49	-0.0002	0.0002
4094	995.352	5006.433	101.49	-0.0003	0.0003
4095	995.334	5006.387	101.49	-0.0007	0.0007
4096	995.317	5006.34	101.49	0.0001	0.0001
4097	995.299	5006.293	101.49	0.0000	0.0000
4098	995.281	5006.246	101.49	-0.0001	0.0001
4099	995.264	5006.199	101.49	0.0007	0.0007

4100	995.263	5006.199	101.44	-0.0002	0.0002
4101	995.281	5006.246	101.44	-0.0001	0.0001
4102	995.299	5006.293	101.44	0.0000	0.0000
4103	995.317	5006.339	101.44	0.0005	0.0005
4104	995.335	5006.386	101.44	0.0006	0.0006
4105	995.352	5006.432	101.44	0.0001	0.0001
4106	995.37	5006.48	101.44	-0.0002	0.0002
4107	995.388	5006.526	101.44	0.0003	0.0003
4108	995.406	5006.573	101.44	0.0004	0.0004
4109	995.423	5006.62	101.44	-0.0004	0.0004



Appendix H – Chainage and Offset Report, Terramodel

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SMK Consultants Pty. Ltd.
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Tuesday, October 20, 2009 5:47:01 PM

 PROJECT: roject Part 2\Jeff Dissertation\Encroachment\Trimble
S6\Trimble S6.pro
----------------------------------------------------------------------
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                                ALIGNMENT REPORT

Alignment Name: Free Pts

Point Number      Description      Chainage     Easting      Northing
Elevation
       Offset
----------------------------------------------------------------------
-----------
    1000          WAL                 0.003      996.714      1006.897
102.588
WAL    0.003
    1001          WAL                 0.005      996.714      1006.894
101.385
WAL    0.002
    1002          WAL                 2.646      996.714      1006.892
100.209
WAL    2.640
    1003          WAL                 2.649      996.669      1004.252
102.590
WAL    0.003
    1004          WAL                 2.658      996.670      1004.249
101.389
WAL    0.009
    1005          WAL                 3.083      996.679      1004.250
100.200
WAL    0.424
    1006          WAL                 3.088      996.431      1003.906
100.191
WAL    0.006
    1007          WAL                 3.093      996.425      1003.906
101.391
WAL    0.004
    1008          WAL                 7.681      996.422      1003.909
102.591
WAL    4.588
    1009          WAL                 7.684      991.834      1003.970
102.591
WAL    0.003
    1010          WAL                 7.686      991.832      1003.972
101.384
WAL    0.003
    1011          WAL                 8.009      991.829      1003.973
100.190
WAL    0.322
    1012          NS                 16.916      992.071      1003.760
100.101
NS    8.908
```

1017	WAL	16.919	983.174	1004.194	101.381	WAL	0.003
1018	WAL	16.925	983.177	1004.195	102.589	WAL	0.006
1019	WAL	30.461	983.172	1004.191	100.201	WAL	13.536
1020	EVE	33.537	996.696	1003.616	102.945	EVE	3.076
1021	EVE	39.135	996.754	1006.692	103.206	EVE	5.598
1022	EVE	48.738	992.036	1003.678	102.917	EVE	9.603
1025	WAL	48.754	982.572	1005.306	101.098	WAL	0.016
1026	WAL	48.757	982.577	1005.321	99.893	WAL	0.003
1027	WAL	49.739	982.578	1005.325	98.697	WAL	0.982
1028	WAL	49.761	982.562	1004.343	101.100	WAL	0.022
1029	WAL	49.785	982.563	1004.321	99.890	WAL	0.024
1030	WAL	50.045	982.564	1004.345	98.690	WAL	0.260
1031	WAL	50.049	982.613	1004.089	98.781	WAL	0.003
1032	WAL	50.053	982.612	1004.086	99.892	WAL	0.004
1033	WAL	50.416	982.614	1004.090	101.096	WAL	0.364
1034	WAL	50.421	982.977	1004.083	101.099	WAL	0.005
1035	WAL	50.425	982.973	1004.080	99.890	WAL	0.004
1036	WAL	53.616	982.975	1004.083	98.697	WAL	3.191
1037	WAL	53.619	986.166	1004.093	99.899	WAL	0.003
1038	WAL	53.627	986.168	1004.095	98.785	WAL	0.008

```
    1039          WAL                 53.696      986.161      1004.090
101.103
WAL    0.069
    1040          WAL                 53.702      986.206      1004.037
101.104
WAL    0.006
    1041          WAL                 53.712      986.201      1004.033
99.897
WAL    0.009
    1042          WAL                 57.416      986.209      1004.039
98.773
WAL    3.705
    1043          EVE                 60.866      982.511      1003.802
101.457
EVE    3.450
    1044          EVE                 65.122      985.961      1003.748
101.450
EVE    4.256
    1045          EVE                 65.473      982.545      1006.286
101.659
EVE    0.351
    1046          NS                  72.289      982.300      1006.035
98.620
NS    6.816
    1052          NS                  72.289      988.712      1003.725
98.611
NS
```

Appendix I – Encroachment Plan